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Sustainable Water Management Strategies for the Farming Village of Adghagh, Morocco

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Abstract

This report examines the current water management strategies implemented within the agrarian village of Adghagh, Morocco. As drought continues to undermine Morocco's agricultural sector, the village's water sources are being depleted and villagers are forced to redrill wells in search of more water. Because drilling to great depths is expensive, and because ultimately the water resources of the region are limited, the goal of our project was to evaluate water use and consumption within the village and propose a series of short-term and long-term solutions that could both in terms of water conservation and economic efficiency potentially alleviate the situation both resourcefully and economically.

Executive Summary

Situated in the Middle Atlas Mountains of Morocco, twelve kilometers north of the small town of Ifrane is the agriculturally based village of Adghagh. For years the village's people relied on a large centrally located reservoir built by the French for both irrigation and revenue from tourists. However, over the past year the water within the reservoir has completely dried up as regional drought has prolonged almost a decade and as villagers have over-extracted water from the ground.

With their main source of water eliminated, residents of Adghagh must now resort to alternative sources of water. Over the past few months, villagers have drilled deeper wells to reach sources of water lower in the water table; however, drilling to such depths is very expensive, and as time progresses and wells run dry, only the wealthy can afford to continue drilling wells. At present, the people of Adghagh must walk over 2 kilometers to retrieve water for drinking and rely primarily on precipitation for crop irrigation. Generally either children or women are sent to retrieve the water for drinking, taking school-time away from children and time which could be spent doing other productive tasks away from women.

In hopes of alleviating the current situation, the Peace Corps has sent volunteer Josh Cabell to the village to collect data, evaluate the situation, and propose measures to increase the village's water supply. For our project, we worked with Josh Cabell in

Adghagh to assist him in evaluating and documenting the situation, compiling our own data, and then presenting the villagers with a comprehensive list of short-term and long-term solutions that we found to be most promising for easing the water crisis of their village.

Over the course of the seven weeks we spent in Morocco, we visited the village a total of three times where we took a tour of the village, sat in on a town meeting to hear the opinions of the villagers on the current water situation, and GPS mapped sources of water within the village. We were also able to facilitate a survey through our Peace Corps Volunteer, which evaluated the current methods of irrigation, the water supply, and the hopes that each village family had for the future in terms of water management. To supplement our visits to the village, we performed extensive research searching through library periodicals, records of past water conferences at Al-Akhawayn University, online databases, and book collections. We also benefited from discussions with Drs. John Shoup and Eric Ross, a geographer and anthropologist at Al-Akhawayn who are experts in the field of water-use in Morocco.

At the end of our research, we concluded that it would be most beneficial for the villagers of Adghagh to implement a series of both short-term and long-term measures to address the water crisis in the village. The proposed short-term solutions are intended to sustain the village for the near future while long-term ecologically sustainable solutions can be implemented and given time to take full-effect.

We have recommended an immediate short-term solution of investing money into drilling a deeper well that would be pumped by the use of solar energy. We believe that utilizing a form of sustainable energy makes it more likely that an NGO will be willing to fund the project, which the villagers otherwise cannot afford. Further environmentally sustainable recommendations for long-term solutions to the water shortages in Adghagh included collecting precipitation (rainwater and snow) for household use, primarily drinking water, implementing new crops that will conserve water and sustain the village's economic stability, and improving methods of irrigation by more widely adopting drip irrigation and improving the efficiency of modular pipe irrigation.

All research and recommendations, including a PowerPoint presentation on the subject, are available to Peace Corps Volunteer Josh Cabell, and through him, to the people of Adghagh. Within the next year, it is hoped that in collaboration with the Peace Corps, the villagers of Adghagh will be able to produce a grant proposal utilizing our report soliciting funding for some or all of the solutions we have recommended.

Acknowledgements

Without the assistance of many different people and organizations the completion of our project would not have been possible. We would like to take this opportunity to recognize each of the following individuals and groups:

Sponsors:

- Peace Corps volunteer Joshua Cabell, for educating us on the needs and desires of the Adghagh villagers, the area's history and its natural resources, and sharing with us his willingness to make a difference in the world.
- The staff of Al-Akhawayn University for welcoming us into their community and providing us with the resources and environment necessary to complete our project.

Liaisons and Advisors:

- Professor Bland Addison for accompanying us on preliminary trips to Adghagh, directing us to valuable sources of information, for providing us with feedback on each draft of our paper, and for documenting our IQP experience with endless amounts of group pictures.
- Professor Tahar El-Korchi for introducing us to the Moroccan culture and applying his knowledge of Moroccan society to suggest recommendations for our project

Information Resources:

- Houssam Jedda, our Moroccan friend and colleague of Al-Akhawayn University for sharing his understanding of the Moroccan culture, helping us overcome communication barriers between the people of Adghagh and our group, and for sharing his immense enthusiasm for helping the people of his country.
- Professors John Shoup and Eric Ross of Al-Akhawayn University for sharing with us their indispensable knowledge of Moroccan customs and history, and for traveling with us on our trips throughout the country.
- Professor Jack Kalpakian of Al-Akhawayn University for supplying us with helpful data on the current water supply situation present in Morocco.

And finally, we would like to thank the villagers of Adghagh for their overwhelming hospitality, immediate acceptance into their community, and enthusiastic support of project objectives and progress. We wish only the best for you and hope that in the near future our project has a positive impact on your village and your canals will see water once again.

Authorship

This project required a great deal of research from a variety of sources including scholarly journals, books and collections from the Al Akhawayn University library, expert opinions from the Al Akhawayn faculty, discussions with our Peace Corps Volunteer, and firsthand accounts from villagers in Adghagh. While this research and related writing was often divided among team members, no part, section, or chapter was without contribution from the entire team. The following portions of the report were first written individually and have since been revised by the rest of the team.

Andrea Bisson: Abstract, Executive Summary and Sections 2.2, 2.3, 2.5, 2.7.1, 2.8 of the Background Chapter.

Paige Bourne: Chapter 1, Section 2.6 of the Background Chapter, Sections 3.2 and 3.5 of the Results and Analysis Chapter, Chapter 4.

Dan Hassett: Sections 2.1, 2.4, 2.7.2, 2.7.3 of the Background Chapter, Sections 3.1, 3.3, 3.4 of the Results and Analysis Chapter, Appendices, and final formatting.

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Nomenclature

°C – Degrees Celsius
DC – Direct Current
°F – Degrees Fahrenheit
FAO – Food and Agriculture Organization (United Nations)
g – Gram (Mass)
GWP – Global Water Partnership
HDI – Human Development Index
IQP – Interactive Qualifying Project
km^2 – Square Kilometers (Area)
LCU – Local Currency Unit
m^3 – Cubic Meters (Volume)
MENA – Middle East and North America
NGO – Non-Government Organization
ONEP – Office National de l'Eau Potable
PV – Photovoltaic's
REI – Regie des Exploitations Industrielles
USD – United States Dollars
WB – World Bank
IWMI – International Water Management Institute
WWC – World Water Council

Chapter 1: Introduction

Situated in the heart of the Atlas Morocco, the agriculturally based village of Adghagh is constantly faced with the impending threat of indefinite drought. As global warming forces average temperatures to rise and annual precipitation numbers to fall communities located closer to the equator, like Adghagh, must adopt techniques to either conserve the water they have or acquire additional crop and potable water from elsewhere. This project collaborated with the Peace Corps Volunteer in Adghagh, Josh Cabell, to examine increasing water shortages within the village, compile short-term and long-term solutions to the water scarcity facing the villagers, and provide recommendations for improving existing methods.

Adghagh is located in a portion of Morocco known as the *Middle Atlas Mountain Range*—a large region which varies greatly in climate and covers 23,000 square kilometers. While more mountainous areas contain indeciduous forests, the foothills are notable for their arid land. During winter months, regional temperatures plummet to sub-zero levels, while in the summer temperatures climb nearly as high as those of the Sahara desert in southern Morocco. Morocco's yearly rainfall average is slightly less than 400 mm, or about a third of the average yearly rainfall in Massachusetts. Because climate varies drastically by season, it is difficult to find crops that are able to withstand both extremes (Cabell).

Located twelve kilometers north of the resort city of Ifrane, Adghagh is home to the descendants of three extended Berber families: *Ait Lahcenou Brahim*, *Ait Hassou*, and *Ait Amerou Aissa*. Up until a little more than a century ago, the area around the village was used for grazing in the summer months, with people descending to lower elevations in the winter to find a better supply of grass. Since the days of transhumance goat and sheep farming, permanent settlements have been established in the area and its people make a living using the land to cultivate crops. Adghagh's main crops are wheat and barley; fruits and vegetables can also be grown, but only when planted in relative close proximity to a water source, such as a well or spring. Due to the lack of water and the rocky nature of the land, crops that ultimately earn more money, such as fruits, are difficult to grow.

Figure 1: Adghagh at Sunset

Until only several months ago, Adghagh profited from a spring fed river originating in the middle of the village. When the potential of the spring was recognized by Morocco's federal *Water and Forest Department* about twenty-five years ago, a dam, or *barrage*, was built to create a small lake in hopes of transforming the area into a resort destination. This investment attracted a wealth of tourists to the village for fishing, and produced substantial revenue for the village (Cabell).

Unfortunately, within the past five years the lake and spring, which formerly served as the village's main sources of irrigation water, have both completely dried up. This elimination of one of Adghagh's most valuable agricultural and economical resources has been detrimental to the village's ability to survive. Though in some areas of the village there is enough water to cultivate crops such as potatoes and onions, the main staples of the village remain wheat and barley—crops which require lesser amounts of hydration.

In an attempt to alleviate these constraints upon agricultural production, both the town and wealthy families drilled wells to supply water for drinking, livestock, and irrigation purposes. Unfortunately, as the area's water table is depleted, these wells, some dug as deep as 100 meters into the earth, are quickly running dry. This has left only the better off families wealthy enough to drill deeper with water access while those with lesser financial means search frantically for alternative methods of irrigation. Yet soon the water table will have dried up to the extent that even those with money will be unable to excavate any further amounts of water from the ground (Cabell).

The village's irrigation system utilizes a series of canals set up through the village but without the spring as a source they have all run dry. Although the town also has a water tower, it is pumped by diesel fuel and is only of use to those who can afford to purchase that increasingly expensive commodity; their money gives them greater access to water. Though the water tower is engineered to reach three faucets within Adghagh, either the piping has been cut off by those living close to the tower in order to better meet their own needs or the faucets no longer function.

Those who walk on foot or by donkey to the tower itself encounter a separate set of problems. The tower pumps water slowly so it takes a long time for the tower to fill. The well supplying water to the tower also was not drilled deeply enough and is not expected to sustain itself much longer.

Under these conditions, the people of Adghagh have been forced to prioritize their need for water. At the current time, the main concern of the villagers is obtaining enough water to irrigate crops and water livestock. Although the village still has a relatively accessible source of drinking water, it requires that either children or women walk several kilometers to reach it. This often takes children out of school or women away from other tasks which could be accomplished within the village, including more economically beneficial uses of their labor.

The Peace Corps has collaborated with leaders of the community to organize a project that will search for a solution to the village's inconvenient accessibility to water sources. Ideally, such a solution would utilize the current canal system while at the same time bring water to the village through public or private faucets. Developments in the projects thus far include drilling a deep well to distribute water through the pre-existing canal system to each of the three families of Adghagh. Once the water reaches each of the families, a reservoir, or place to collect water on each property would be erected so that there is no need for water to be pumped continuously from the main source. Ideally, both solar and wind power would be used to fuel the system because the village is situated at a high altitude; this would give the solar panels optimum

Figure 2: An Example of Canal Irrigation

exposure to sunlight and the wind-powered generators the greatest access to gusty winds (Cabell).

However, plans for the proposed irrigation system have not yet been finalized by the villagers and Peace Corps. This is partly due to fears that within a few years of the project being completed, the technology may malfunction and no one residing in the village will have the knowledge to repair it. In this scenario, it is likely that the villagers would revert back to the current, less efficient and effective methods of irrigation. Unfortunately neglecting to upkeep technology has occurred all too often with developmental projects in the past and large amounts of money invested in such projects have gone to waste.

Thus, community members and Peace Corps Volunteers continue to look into other water preserving techniques. These include drip irrigation, rainwater or snow storage, genetically engineering crops to be drought resistant and changing to crops that require less water. When considering the adoption of any of these methods, it is important to remember that it is likely the people of Adghagh may be culturally resistant to change in customary agrarian practices.

The water shortage encountered in Adghagh is certainly not only a local problem; due to the nature of Morocco’s climate and increasing amounts of global warming, a lack of water has set the Moroccan people as a whole on a quest to find an economically feasible solution capable of curing the nation of this life-threatening ordeal.

Chapter 2: Background

Over the last several decades, Morocco and North Africa in general have experienced rapidly decreasing water supplies due to drought and the availability of water for use in irrigation especially has become a serious problem. Limited quantities of irrigation resources and inefficient use of the water available are causing a positive feedback loop by first decreasing crop yields, resulting in stagnant income, which further limits capital needed for improvements necessary to irrigate crops more efficiently. In order to resolve the current water shortages troubling Adghagh, it is important to consider techniques which conserve the present water supply and methods that increase the amount of water reaching crops.

Perhaps first, the most obvious cure to the impending water crisis should be investigated—sustaining the current water supply for as long as possible through water conservation. The amount of water currently used for crop irrigation by Adghagh could be reduced through water-preserving techniques such as drip irrigation or conservation tillage. By reducing the volume of water used in irrigation, the villagers will have greater access to water for personal consumption, irrigation, and livestock. All of the water problems in Adghagh must be understood in the context of the on-going crisis of global resource exhaustion we all face.

2.1: Drought on a Global Scale

Throughout history, associations formed between nations have come together to discuss and address problems and issues of great concern to the world. Water scarcity has only recently gained popularity as an active topic of debate, joining subjects such as poverty and disease which have often been cited as subjects of high priority (Salman M.A.).

Figure 3: Soil Dehydrated by Drought

Although many scholars recognized the threat of impending world drought several decades ago, international institutions refused to realize the severity of the problem until the late 1990s when the World Water Council (WWC) and the Global Water Partnership (GWP) were formed. The two organizations were arranged to transfer the responsibility of world water management to a group that would be separate from the United Nations and whose focus would solely be water oriented. Additionally, a third organization, the *Club of Tokyo*, brought together fifteen internationally recognized water management specialists to address the future global water shortage. Collectively, all three organizations recognized and publicized the severity of future world water issues for the first time (Salman M.A.).

The Current Water Supply

Currently, the world has approximately 37 million Mkm^3 of freshwater at its disposal, 78 percent of which is trapped in the polar icecaps. The majority of the other 22 percent of freshwater is located underground, and is not easily accessible to those who need it. As groundwater extraction rates increase, the area's water table is becoming depleted. As a result, countries worldwide, such as Morocco, are beginning to feel the effects of the world's decreasing water supply. Additional factors, particularly global warming and an increasing global population, exacerbate the planet's already dwindling supply of water (Salman M.A.).

Global Warming

Global warming occurs when carbon dioxide is released into the air and the molecule accumulates in the earth's atmosphere, causing for sunlight to become trapped within it. Because an increasing level of heat is unable to leave the atmosphere, the average temperature of the earth rises slightly each year. Consequently, the earth experiences changes in climatic conditions that result in a redistribution of water supply and both

Figure 4: CO2: The Cause of Global Warming

global and localized temperature shifts. It is predicted that in the coming years, countries such as the United States, China, and Uganda will experience condition changes conducive to agriculture, whereas countries such as India, South Africa, and Uganda will encounter the contrasting transformations (Salman M.A.).

World Population

In the late 20th century, over the course of 12 years the population of the world increased from 5 billion to 6 billion—a rate astronomically higher than that of past century population growth rates. Although the number of people is rapidly increasing, precipitation is not. With an expected world population of 8 billion people by 2025, the issue of finding additional water sources to support the burgeoning population is of even more dire concern (Salman M.A.).

2.2: Drought in Morocco

Subject to the arid conditions and limited rainfall typical of Northern Africa, Morocco is particularly at risk for drought and a prolonged lack of water. According to a study carried out by the International Water Management Institute (IWMI) located in Sri Lanka, Morocco is characterized as a *Group II Country*, meaning that by 2025 it will need to

Figure 5: A Barren Irrigation Ditch

increase their supply of water by at least 25 percent to keep pace with the needs of their population. The other countries included in the same group were Argentina, Australia, Bangladesh, Brazil, Ethiopia, Mexico, Myanmar, Nigeria, the Philippines, Sudan, Thailand, Turkey, and Vietnam (Merrett).

As a Group II Country, Morocco is considered to be at medium risk for severe future water shortages. Those that were designated a *Group I Country*, were considered to be in the worst position for future water scarcity and were predicted to be unable to supply their people with water in 2025. Group I Countries included countries such as Algeria, Egypt, and South Africa. Those categorized as, *Group III Countries*, were said to be in the best position; by 2025, they would only have to increase their country's water supply as recorded in 1995 by less than 25 percent. Countries such as Canada, France, the United Kingdom, and the United States were included in this group (Merrett).

Effects of the Colonial Regime

Many argue that the effects of the French and Spanish colonial rule over Morocco throughout the past century have left its infrastructure ill prepared to battle the effects of drought (Swearingen). When the colonial regime forced Moroccans onto plots of land even smaller than those they had previously owned, they further reduced the amount of land available per citizen. As a result, fallowing, which is when farmers leave a plowed area unseeded for a season so that the area collects residue and moisture for the next, was made economically unfeasible. Although the Moroccan population has spread out from the colonial plots of land since independence in 1956, many cultivated areas still suffer from overuse and the repeated plantings. The need for fallowing still exists today; as of

1988 the use of fallowed cereal cropland was 20 percent lower than what it was in the late 1930s (Swearingen).

Irrigation and Drought

Further exacerbating Morocco's drought problem is the lack of irrigation evident throughout this agriculturally driven nation. Although 68 percent of the country's land is devoted to agricultural uses, only 15 percent of the land is irrigated. When compared to the World Bank's collective group of Middle East and North Africa countries, which have an average of 23 percent of collective land used for agriculture and 32.2 percent of collective land irrigated, it is clear that Morocco lags behind other countries in the realm of irrigation (The World Bank).

In addition, the World Bank's *Lower-Middle Income Group* of countries, on average devotes 43 percent of its land to agriculture purposes, and irrigates 24.3 percent of its land. Although, the amount of land used for agriculture is almost double that which is irrigated, the difference between Morocco's respective statistics is over 30 percent worse (The World Bank).

Urban vs. Rural Access to Water

It is also important to note that the difference in access to an improved water source between urban and rural areas of Morocco is drastic. According to the World Bank, as of 2007, 99 percent of the country's urban population had access to an improved water source in contrast to only 56 percent of the rural population. Again, to put this figure in perspective the World Bank calculated the averages of both the MENA group and the

Lower-Middle Income Group. In the MENA group, 81 percent of the rural population had access to an improved water source, versus 96 percent of the group's urban population. Of the Lower-Middle Income Group's rural population, 71 percent had access to an improved water source in comparison to the 94 percent of the urban population (The World Bank).

According to these statistics, the lack of access to water sources for Morocco's rural population is much greater than that of other countries of similar economic status. Certainly, the limited water access plaguing Morocco has left villages such as Adghagh at the hands of impending drought and without traveling to more distance sources, devoid of water (The World Bank).

Morocco's Water Threshold

Although the scarcity of water within Morocco is evident throughout the country, there are certain areas which have much better access to water than others do. On average, the northwestern parts of Morocco receive from 500-2000 mm per year of precipitation; this is in stark contrast with the southern and eastern portions of Morocco which expect less than 100 mm each year (Benazzou). Moreover, because the amount of annual precipitation received by any area is variable, it is impossible to depend upon any amount of precipitation; this is especially pertinent in a developing country where aridity can plunge its people into extended periods of recession.

Groundwater within Morocco also varies greatly between regions with different climatic zones. As of the early 1990s, groundwater in the Mediterranean zone represented only 4 percent of Morocco's total groundwater. The *Atlantic Zone* accounted for 52 percent, the *South Atlas* contained 19 percent, and the *Occidental* region housed 17 percent of the nation's groundwater supply. Predictions made for distribution of groundwater in 2020 were roughly the same (Benazzou).

Critical vs. Actual Threshold

The *critical threshold* of water is defined as the average volume of water that a person consumes over the course of a year. This value is designated as 1000 m^3 per person per year (Benazzou).

The *actual threshold* of water is defined as the average amount of water that is consumed by the people of a region over the course of a year. As a result of Morocco's water shortage, the actual threshold of Morocco is lower than the critical threshold and as of 1996 was estimated to be 830 m^3 per person per year. As water supplies continue to dwindle, the actual threshold is predicted to drop even lower to 411 m^3 per person per year in 2020. This decrease in actual threshold can be attributed to a variety of factors including population growth, improvement in economy, urbanization, and pollution (Benazzou).

Similar to the world's problem with population growth and water supply, Morocco's population has been increasing by a yearly rate of 3 percent and has grown from 11,626,470 in 1960 to 29,891,708 in 2004. With no increase in annual precipitation to supply the exploding population, the amount of water available to each person will decrease sharply.

Furthermore, over the past quarter-century, the economy of Morocco has been improving rapidly. In 1975, the nation had a *Human Development Index* (HDI) of 0.426

as compared to 0.630 in 2004. Although this economic progress is certainly beneficial to the country’s activities and population, it has been detrimental on the country’s water supply. As the economy improves, consumption also increases because people have more money to spend. Because a portion of this is spent to obtain water, the country’s water supply is further stressed.

In addition, an increase in urbanization has also put stress upon Morocco’s water supply. The percentage of urbanization has increased by over 25 percent between 1960 and 2004. As cities expand, a greater amount of water is used to supply urban services and again, stress is placed upon the country’s water supply.

Finally, pollution is also threatening the country’s water supply. As Morocco continues to develop with few pollution laws on the books and lack of enforcement in all sectors, levels of pollution present in certain water sources are rapidly increasing. As of 2000-2001, 45 percent of Morocco’s freshwater and 51 percent of its groundwater were designated as *low quality*. Not only is pollution harmful to the environment, but it also eliminates large portions of water from Morocco’s water supply.

Drought in Adghagh

Located in the Atlas Mountains of Morocco, Adghagh is susceptible to the arid, drought plagued summers characteristic of the region. Because the Moroccan village is situated in a rural area of the country, its access to water is limited and villagers are often required to walk several kilometers to reach suitable drinking water (Cabell).


Figure 6: An Apple Orchard in Adghagh

In order to successfully plant and harvest a season of crops, the people of Adghagh must practice *full irrigation*. The term full irrigation refers to the growth of crops which would be impossible without the addition of water by humans. This type of irrigation is in contrast to *supplementary irrigation*, where water in addition to precipitation is only necessary when one wants to increase the season's yields. In supplementary irrigation, crops could still be grown without additional water, but water can be added to encourage additional growth. Full irrigation is expectedly typical of arid climates, such as that of Adghagh, while supplementary irrigation is typical of regions that receive ample rainfall (Merrett).

2.3: Underground Springs and Water Tables

Over the past twenty-five years, Adghagh's reservoir has supplied the village with water for irrigation and drinking, and drew tourists from all over for recreation. Gradually over the last several years, the reservoir has receded, and more recently it has completely dried up. Beyond a decrease in precipitation, other causes of the lowering water table include the over extraction of groundwater by villagers and monopolization of the water supply by nearby commercial sized apple orchards. When the reservoir was verdant, it was sustained by springs located at its southeastern corner (See Appendix A). At this time, when water was taken from the reservoir for irrigation and drinking purposes, it was easily replenished by these springs; however, as the water table decreased all of these springs ran dry and the villagers have been left without a reliable water source to depend upon (Meeting: 4Sept08).

The water table of an area is generally supplied by an *aquifer*, an underground rock layer that contains water and releases it inappreciable amounts. Water is located within porous spaces in this layer consists that connect to allow water to flow freely between them (Britannica). Normally the most upper portion of groundwater is known as an *unconfined aquifer*, whose upper boundary is often referred to as the water table. Unconfined aquifers are free flowing bodies of water that receive groundwater recharge directly from the surface and are typically located above a non-porous rock layer. This rock layer, known as an *aquitard*, restricts flow from the above aquifer to the *confined aquifer* below (USGS).

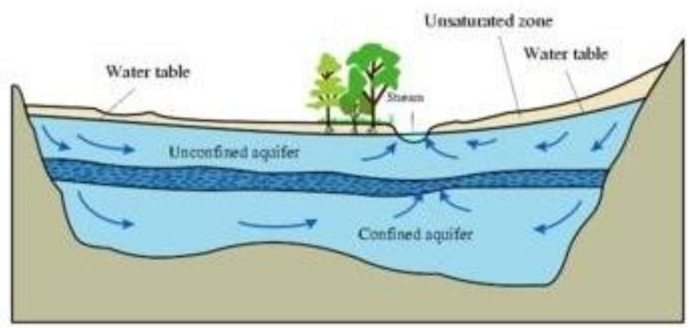

Figure 7: A Diagram Showing Underground Aquifers

Extracting water from either type of aquifer can be done in a variety of ways. *Artesian pressure* will often bring water to the surface from a confined aquifer when the pressure exerted by groundwater recharge on the aquifer is greater than atmospheric pressure. Natural springs are the result of this pressure difference enabling water to travel nearly one thousand feet to the surface without the use of pumps. Often times the spring begins flowing through a crack in the rock layers above the aquifer and overtime expands into a pathway up to several feet in diameter. This principle of pressure can be explained easily by categorizing the earth's sub-surface into two types. In zones of confined aquifers, the water is often in a saturated state. A saturated zone is water-filled soil underground. This often exists under a pressure greater than that of the atmosphere and causes the water to want to escape. Unsaturated zones are where the porous area of rock or soil is only partially occupied with water and exists under suction. The exertions of positive pressure on the confined aquifers are the cause of natural springs (USGS).

In the absence of natural springs, water can be extracted by artificial means. Methods of digging and drilling wells have been in use for thousands of years and are used to effectively retrieve groundwater when above groundwater sources are unavailable or inconvenient. In the past, the average groundwater well has had a depth no greater than fifty

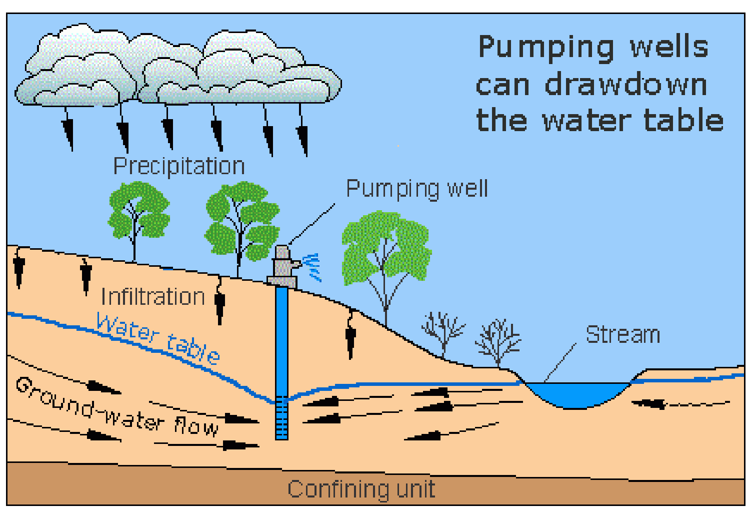

Figure 8: Diagram Explaining the Effect of Wells on Groundwater

feet and a diameter of at least four. However, as technology improves wells can be artificially drilled to be much deeper, with sub-urban wells in the United States reaching depths from one hundred to three hundred feet and able to supply the water needs of three families comfortably (Treskatis). Additionally, when commercial or agricultural purposes call for greater amounts of water, wells reaching six hundred feet are not unheard of. In the most extreme cases, such as providing a well for a large population or for industrial purposes in an area where the aquifers are unusually low, you may see wells reaching depths of three thousand feet. It is important to note that wells of this depth are very rare because the cost to drill and operate pumps which can fight the force of gravity that far into the earth are expensive (Baroudy).

Although operating wells to provide water can be useful, there are also several problems associated with the practice if employed incorrectly. One of the biggest troubles facing the heavy use of wells is their unreliability if they are drawn from too often. When used as a crutch when facing water scarcity, the wells will not recharge correctly, causing what is known as a *cone of depression* (USGS).

Another problem that is often encountered is that they can decrease the existing water levels of the water table. Except in the extreme cases noted above, wells most often driven or drilled at depths within the upper level unconfined aquifers. Due to the fragile nature of water wells, when tapping into these sources in arid regions, such as Adghagh, it is crucial to

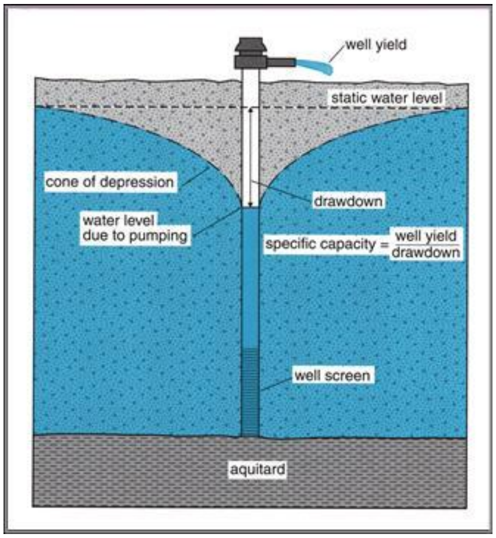

Figure 9: A Well and Its Surrounding Cone of Depression

understand the dynamics of well withdrawal and replenishment. The groundwater in arid regions is very delicate because it is generally only replenished by rainwater and snow, so it is necessary to monitor the levels of withdrawal carefully (Salman). Therefore, when other water sources such as natural springs dry up in the area, it signals that the water table and artesian pressure are decreasing. When this happens, communities have only the choice to drill deeper. After other sources like springs dry up, and water must be extracted from great depths, the water table will continue to be lowered to a greater extent because the rate of withdrawal will still be greater than the rate of replenishment (Groenfeldt).

The Springs and Water Table in Adghagh

Over the last several years, the water table of Morocco has been decreasing significantly. This is partly because Morocco has virtually zero annual river inflow, but has 0.3 billion m^3 outflow to other countries and the ocean, putting them at a distinct disadvantage. Coupled with the drought which has stressed Morocco over the past thirty years, it is extremely difficult for Morocco to sustain a developing agricultural system while feeding a growing population. In 2003 the percentage of land facing water scarcity reached 42.2 percent. This combination of arid weather and great need for water withdrawals are posing a severe threat to the nation and especially to small area farmers who are unable to economically afford digging deeper wells so frequently. These Moroccans facing water scarcity must also confront accelerated sinking groundwater level and a financial struggle to run water pumps needed to retrieve water deeper than ever before (Making the Most of Scarcity).

Figure 10: The Now Empty Reservoir in Adghagh

More specifically, the farmers of Adghagh are also struggling retrieve water from an area that has a declining water table. Over the last approximately five years, the natural springs which had fed the reservoir area of their village have dried up because the artesian pressure of the area has immensely decreased. Not only had this reservoir been the farmers' primary source of irrigation water over the past fifty years, but it also attracted a tourist clientele that further benefited their economic status (Cabell).

2.4: Water Regulation in Morocco

Up until the 1950's, the Moroccan water supply was controlled by the Regie des Exploitations Industrielles (REI), which was replaced by the Office National de l'Eau Potable (ONEP), the agency that still regulates the country's water today.

Since the association's creation, it has built upon urban water systems to reach rural areas and has implemented several successful policies. In 1967, ONEP passed a policy which set a goal to irrigate one million hectares of land by the year 2000. They passed an additional policy in 1986 which set another goal of building at least one dam every year until the year 2000. Since then, dams have been constructed throughout Morocco annually so that water is held back, collected for communities, and more easily distributed through canal and piping systems. Although the construction of dams has not been amiable to the environment, in several aspects it has improved the nation's water regulation (Benazzou).

A third policy, which is perhaps the most significant of the three, is the *Water Law* which was implemented in 1995 and divided Morocco's water supply into nine hydrographic basins. Each basin is managed by a group of individuals who control distribution of the basin's water, storage of the water, groundwater, the quality of water, and evaluate the region's risk for flood and water-related emergencies (Benazzou).

The Sebou Basin

Located in central Morocco, the *Sebou Basin* is the geographical location including Adghagh. As one of the largest basins in the country, it contains approximately 5000 m^3 of water, comprising 28 percent of Morocco's freshwaters and 20 percent of its groundwater.

While spanning approximately 40,000 km^2, the Sebou basin supplies water to 6.7 million people. The basin services mostly the rural population, where 57 percent of its water goes to rural areas and 22.7 percent to urban areas (Sebou source).

Each basin in Morocco is composed of aquifers, or sub-basins, which are small sections of a much larger parent basin. The village of Adghagh receives its water from the *Atlasique aquifer* (Sebou source).

In the many decades since its French colonization, Morocco has enacted policies to improve the Sebou Basin. The best known of these projects was known as the *Sebou Project*. Over the years, the project has produced 10 large dams, 44 small dams, the Matmata gallery, and 4 hydropower stations to make the Sebou Basin one of the most significant and largest in the nation (Sebou source).

2.5: Alternative Energy and Systems

Many of the wells in Adghagh are powered by diesel engines. With the recent increase in fuel prices, operating these pumps has become a costly endeavor. In this section, we will explore the replacement of these costly and high maintenance engines with highly efficient and environmentally friendly alternatives.

Solar Energy

Due to the global need to decrease dependency on fossil fuels, the use of alternative energy sources is growing rapidly. Implementing solar energy as a main energy source is an advantageous choice in many areas including the Middle Atlas region of Morocco. The initial costs of installing a solar energy collection system are relatively high, which may deter interest in actually making use of this type of system. Over time though, solar energy systems have a great potential to save money in an environmentally friendly way.

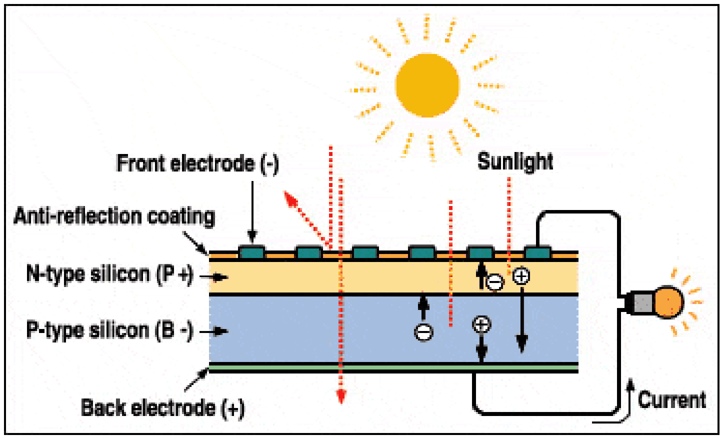

Figure 11: A Diagram Explaining the Transformation from Sunlight to Energy Using Solar Cells

Solar energy systems rely on the principal of *photovoltaics*, or the direct conversion of light into energy. Materials used in solar energy systems often exhibit the property known as the photoelectric effect. This is the property of a material that allows it to absorb solar energy, in turn releasing electrons, which create an electric current. The actual energy-collecting device is known as a solar cell. A cell consists of a thin, specially coated wafer-like piece of a semiconductor material, for example silicon. One side of this ‘wafer’ is positively charged and the other negatively charged in order to create an electric field. The field is created when light hits the wafer because electrons break free of the material. Two electric conductors are attached to the wafer, one to the positive side and the other to the negative side, this creates a circuit, with the electrons that have broken free creating the current.

While individual solar cells will produce energy, they generally do not produce sufficient energy to meet the need of the users. For this reason, clusters of cells are put together to form solar modules, which are then connected to form solar arrays. The larger the surface area of a module or array, the more energy it will be able to produce (Brosius).

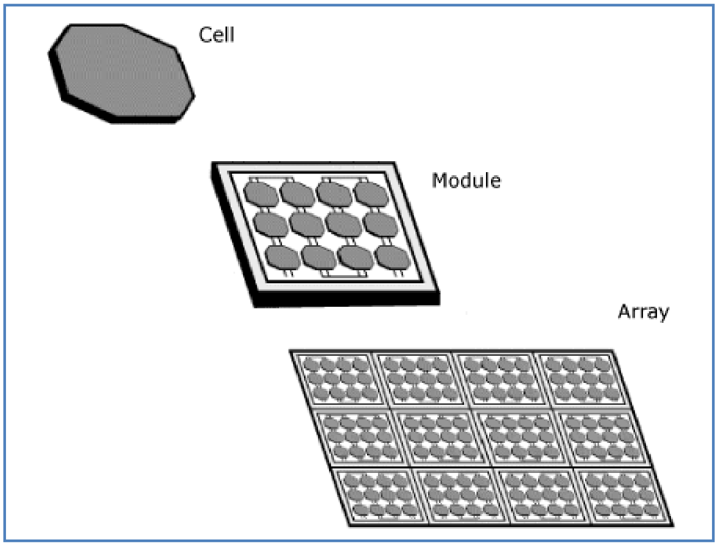

Figure 12: The Three Layers of Parts in A Solar Panel

To have a functioning solar energy system one needs to mount the solar arrays in the proper way. There are a few different types of solar array mounts, each with advantages and disadvantages. The first mounting system is *fixed structure*. This mount can withstand high winds, which is beneficial for the village of Adghagh because of the high winds they experience due to their elevation. The other type of mounting system is *tracking structure*. This structure follows the movement of the sun to achieve maximum efficiency and can be up to 25 percent more efficient than a fixed structure. The disadvantage to this mounting system is that it can cost an additional $400-$800 in the initial costs of a solar energy system. Ultimately it will be up to the users of the solar array to determine which option would be more efficient and cost effective for their needs (Boyle).

Another cost factor that needs to be assessed when implementing a solar energy system is the energy storage. In some systems the arrays store extra energy in a battery in able to provide energy even when solar conditions are not optimal, such as on cloudy days or at night. In a more simplified system there is no battery and energy can only be used during prime solar hours. While this limits the power obtained by the system, the most significant advantage is that without a battery, there tend to be less maintenance problems, and when problems do occur, they can be more easily. In a village such as Adghagh this is very important to consider because it is unlikely that there is anyone in the village that is able to fix problems in advanced technologies such as solar arrays.

The two different types of energy systems associated with solar energy are *battery-coupled* and *direct-coupled*. A battery-coupled system consists of PV panels, a charge control regulator, batteries, a pump controller, a pressure switch and tank, and a DC water pump. This system is advantageous because it collects energy during sunny conditions and stores the extra energy, allowing the pump to run whether or not the conditions are optimal. This means the pump can run even on cloudy or wind-free day. However, there are a few disadvantages associated with the battery-coupled system. Most importantly, when used in conjunction with solar arrays, the battery-coupled system provides 4 less volts than a direct-coupled system on a sunny day. Also, since batteries have a limited life expectancy, battery-coupled systems have greater maintenance costs.

A direct-coupled system simply consists simply of PV modules, which directly provide energy to the water pump. This system can provide nearly one hundred percent efficiency on a sunny day. Due to this efficiency, extra water can be pumped from the well and stored above ground for use on cloudy days or at night. The downside to a direct-coupled system is that the efficiency does vary depending on the sun's location in the sky. Also, while extra water can be pumped above ground for use in sub-optimal conditions, this runs the risk of loss of water due to evaporation or, in the winter months, freezing of the extra water.

Wind Energy

Another form of alternative energy that could be considered for use in Adghagh is wind energy. This could be particularly beneficial in the area due to the high altitude of the Middle Atlas Mountains and the winds that blow across the area frequently.

A wind energy system consists of one or more wind turbines. When the wind blows, it spins the blades of the turbine, which, in turn, spin a rotor that is connected to a generator to create power. This power can be used directly from the generator or it can be stored in a battery similar to the battery that can be used in a solar system (Boyle).

Figure 13: An Example of a Wind Turbine

Wind energy offers many advantages and disadvantages that are similar to those of solar energy. One of the obvious problems is that the only condition that will produce energy using this system is a windy day. Also, this system is rarely used for pumping wells and may not be the most efficient energy system for this situation. While energy can be stored using a battery, this again involves more maintenance that may be difficult in the future (Boyle).

Water Pumps

The needs of Adghagh specifically involve pumping water up to ground level from a well. This is currently accomplished by using diesel fuel, which is both harmful to the environment and is rather expensive. Through the use of alternative energy to power the well pump, money can be saved for the villagers. Both wind and solar energy can be used to pump water from a well in similar manners. There are, however, two different types of pumps and two different pump locations that one needs to choose between when installing a well pumping system.

The types of pumps are known as the *displacement pump* and the *centrifuge pump*. Displacement pumps use diaphragms, vanes, or pistons to seal water in a chamber and force it through a discharge outlet. A centrifuge surface pump uses a spinning impeller that adds energy to the water and pushes it into the system, similar to a water wheel (Selecting a Pump Type).

Pumps can also be implemented in two different environments. Suitable pump locations are either at the surface or submerged. Surface pumps are typically used to move water through a pipeline, good for moving water long distances or to high elevations; submersible pumps are place down and inside the well. Although less accessible for repairs, a valuable advantage of submersible pumps is their natural protection from weather conditions and freezing temperatures associated with being underground.

2.6: Water Conservation

Perhaps first, the most obvious cure to an impending water shortage should be investigated: using water conservation to sustain the current supply for as long as possible.

Conservation Tillage

Throughout history, cultures have devised unique ways to decrease the amount of water needed to irrigate crops during times of drought. The Navajo tribe of western America insulated planted seedlings with sand to protect the seedling's water supply from evaporating. The Navajos would dig a hole in soil, plant the seed, and rather than filling the hole in with soil, use sand (Dalrymple).

Techniques such as this have permeated cultures and nations all over the world to fit the specific climatic conditions of the land. In recent times, the practice of conservation tillage has been utilized in arid climates to retain moisture within cultivated soil. Although several aspects of this practice are not fully developed and its effects are not fully known, the technique may hold promise for drought stricken lands such as those of Morocco. Certainly its application should at the least be considered (Allmaras et al.).

Since the early 1800's, *conventional tillage,* rather than *conservation tillage,* has been used to eradicate residue from the past year's crops. This was often done by using a moldboard plow to invert the soil; although the process consumed great amounts of energy, its advantages were thought to outweigh the cost of fuel and manpower. Conventional tillage is carried out to kill pests, diseases and weeds, decrease the amount of wind and soil erosion, and create the most favorable environment for the next year's seedlings. Of course, the success of the practice can vary based on the crop being grown and its climatic location (Allmaras et al.).

It wasn't until the mid to late 1900's that the opportunities of conservation tillage were considered. By definition, conservation tillage is any type of tillage that conserves either soil or water (Allmaras et al.).

Ironically, the most common practice of conservation tillage is in a sense, the opposite of conventional tillage. Rather than eradicating the residue of past crops from the soil, the residue is left there and serves as a type of barrier between the atmosphere and the seedlings beneath. Seeds are then planted by farming machinery beneath the residue. As a result, the amounts of soil and wind erosion sharply decrease. The layer of residue protects the soil from direct contact with the wind, softening the effects of wind erosion. In the same manner, severe soil erosion is also evaded. When raindrops collide with the soil, the residue lessens their impact, decreasing soil erosion (Allmaras et al.).

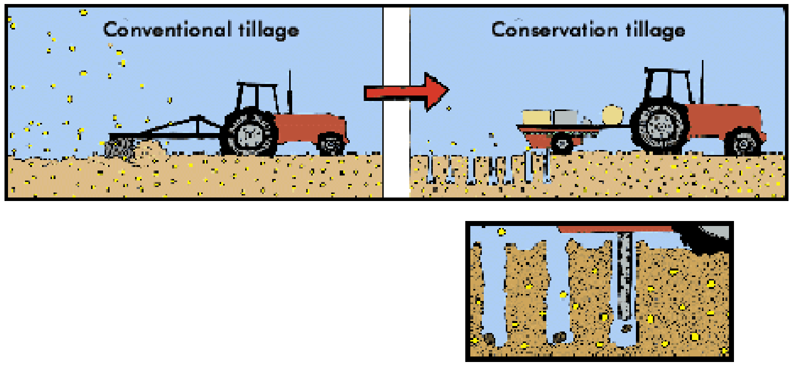

Figure 14: Conventional Tillage vs. Conservation Tillage

The presence of residue also causes less air movement to infiltrate the soil surrounding the seedling, cooling the soil by 3°- 4°C as compared to soil under conventional conditions. It is this characteristic of conservation tillage which makes the agricultural technique so amiable to arid climates. Because the soil is so much cooler, it takes that much more energy for the sun to heat the soil's water to evaporation temperature. Conservation tillage thereby increases the fallowing capacity of the soil—a characteristic very important to Morocco's climate (Allmaras et al.).

In years past, the threat posed by pests and weeds made the practice of conservation tillage impossible. However, with the advent of herbicides and pesticides, the practice was made somewhat feasible and the inversion of soil is not always necessary. But, with the opportunity offered by this new technology, comes at least some measure of uncertainty and difficulty (Allmaras et al.).

Disadvantages to this practice have already arisen. Researchers have found that the residue can prevent fertilizer from reaching the correct depths of soil. As a result, phosphorus from the fertilizer can build up at the surface layer. Because the soil is not inverted, phosphorus and potassium accumulation at this level have also been observed. Either situation may cause hazard to the seedling (Allmaras et al.).

In addition, the drop in soil temperature may cause germination to occur later than usual and depending on the crop being grown could cause harvesting problems (Allmaras et al.).

Yet, the biggest problem farmers seem to face is weed and pest management. Traditional methods of pest and weed management can no longer be applied under conservation tillage, leaving herbicide and pesticide application as the lone option available to farmers. Scientists fear that eventually a pest mutation making it resistant to the pesticide will eventually arise through natural selection, creating an indestructible *super bug*. If all cropland is under the practice of conservation tillage and this occurs, the world will experience a severe famine and be left to deal with acres of diseased crops (Allmaras et al.).

In short, the consequences of conservation tillage are not completely known yet and it is clear that more research surrounding this topic is needed before its practice should be applied vastly. Questions as to the both the short and long-term effects of conservation tillage, economic feasibility, and climatic application are yet to be answered. Still, farmers around the world are experimenting with this method right now and are achieving beneficial results. In the country of Morocco where water is a scarce and expensive commodity, it may be wise to put research and field-testing into this technique (Allmaras et al.).

Drip Irrigation

The current irrigation system supplying water to Adghagh is an open canal network which transports the limited available water from nearby wells to crop fields. This method of irrigation is inexpensive and convenient when there is an abundance of water; however, when facing rapidly decreasing water availability, canal irrigation is comparatively incredibly unproductive (Cabell).

Another form of irrigation, known as *drip irrigation*, may propose a solution to this shortage of water. In addition to being the most cost effective means of irrigation, drip irrigation is easily implemented into third world farming environments due to its simplicity and easy application. There exist three different types of drip irrigation, and the suitability of each depends on the situation one is attempting to address (Knight).

The first and most conventional mode of drip irrigation, *point-source*, utilizes a single output emitter that is attached to a plastic pipe or rubber hose, which can be run either above or underground. The emitters are placed at specific intervals along the rows of crops so that water is distributed directly to their roots (Knight).

Similar to traditional spray irrigation, *microspray* drip irrigation, or the second method of drip irrigation, has a much lower flow rate. Microspray devices can be manually adjusted to output various flow rates, throw distances, and cover angles. While microspray is much more efficient than traditional sprinkler and canal irrigation, it is still susceptible to evaporation and wind (Knight).

Finally, the third method and probably the best candidate for the village of Adghagh is known as *line-source* drip irrigation. This form is similar to point-source drip irrigation, except the pressure compensating emitters are built into the main water lines and are pre-spaced. This method is used to distribute water evenly over a given area and therefore it does not aim emitters at specific plants, but rather distributes water across an entire row of plants, allowing the soil to disburse water to the roots. Additionally, this method is the least expensive of the drip irrigation systems, very easy to install, and the preferred mode of drip irrigation for densely planted fields.

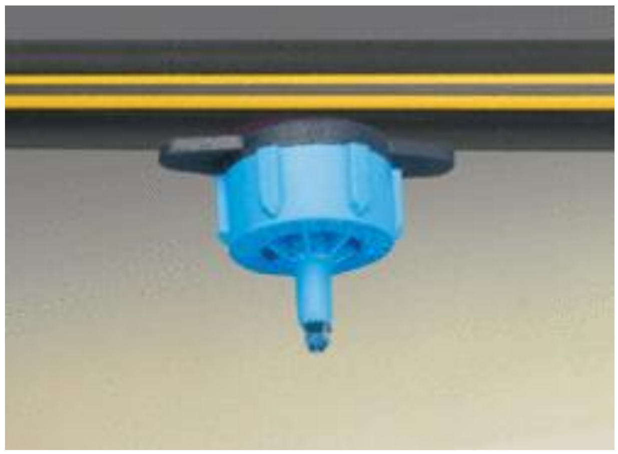

Figure 15: A Single Emitter on a Line-Source Drip Irrigation System

Although the use of drip irrigation dates back approximately thirty years, cost-effective methods by which to apply the practice have only surfaced in the past decade. In the United States, water usage is a sensitive issue and water sometimes is even rationed to farmers. Many countries experiencing severe water shortages have tried or are trying to incorporate systems such as these into the agricultural systems of their country. The benefits of drip irrigation to farmers and their communities can be very significant when the potential for saving scarce resources is considered. In North America, the use of low volume drip irrigation systems have been shown to reduce water usage thirty to seventy percent compared to that of conventional overhead irrigation systems. Considering that even conventional overhead irrigation systems are vastly more efficient then Morocco's current open canal network irrigation, the potential for water efficiency improvement is hard to ignore.

An additional feature of drip irrigation is that it not only allows for the efficient and equal distribution of water, but it also can serve as a mode of transport for delivering fertilizer and pesticides to plants. By efficiently distributing fertilizer, the costs required to supply labor and fertilizer to crops are decreased.

When considering the installation of drip irrigation systems in Adghagh, Morocco, it is very important to consider the water efficiency of the system at hand. It must be noted, however, that if selected there are additional expenses involved in the upkeep of a drip irrigation system; these include installing a proper filtration system to prevent debris from clogging the drip lines, purchasing pumps and elevated water sources, and absorbing the costs of preventive and incidental maintenance.

Water Harvesting

Although groundwater has become scarce in the area of Morocco surrounding the village of Adghagh, the region still experiences some rainfall each year totaling less than 420mm or 16.5 inches (Making the Most of Scarcity). The ability to utilize precipitation for later use is another key element to being less reliant on deep wells to supply drinking water.

Water harvesting, also known as rainwater catchment, has many different techniques; there are some versions that are certainly easy enough for anyone in Morocco to apply to their everyday life, along with people of the village of Adghagh. One of the simplest techniques to harness rainwater is to use the roofs of ordinary houses as catching devices

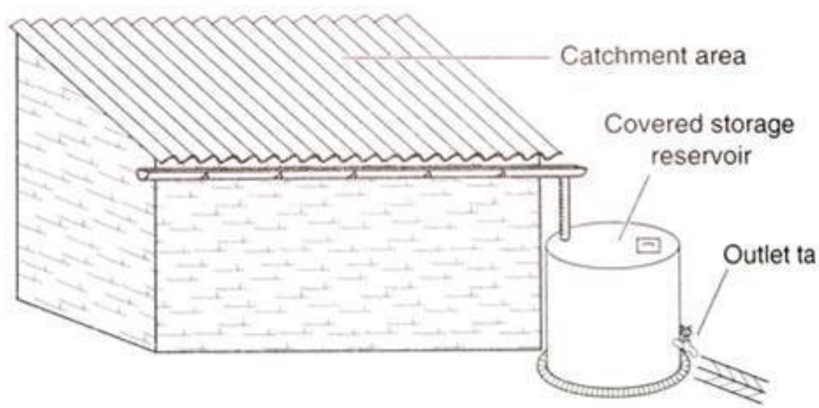

Figure 16: A Diagram of a Simple Water Catchment System

and divert water which would ordinarily hit the ground to a water container such as a large enclosed barrel. Storing the water in a large bucket such as a fifty-five gallon drum would be suitable for smaller houses and larger storage containers would be necessary for larger buildings. The rainwater retrieved from just a small house after one rainstorm can potentially supply drinking water for an entire week until another storm could come to replenish the supply.

2.7: Alternative Crops

Many advocate the position that as the climate of Morocco changes, its crops must also change (Cabell). As global warming forces the temperature of this region upwards, making climatic conditions drier than ever, we must search for crops that are both profitable and resistant to prolonged periods of drought (Mizrahi and Nerd).

However, it is important to remember that Moroccan cereal crops have been traditionally grown for years and altering such a crucial portion of their native culture could be difficult, if not impossible. Moreover, introducing a new product to any market can be extremely difficult and in many cases the product falls from the market within months. Before a decision to cultivate a new selection of crops is made, the *product profit cycle*, or the general sales trend followed by new products must be reviewed (Mizrahi and Nerd).

Product Profit Cycle

When a new product initially enters a conventional market, such as that of Morocco, its price is set low relative to other items so that it is appealing to consumers. This encourages consumers to try the new item even though they have never purchased it before and personally know nothing about its quality. No profit is made at this point. Either one of two things will then happen: the public will take to your product and demand will increase, inversely causing the product's price to increase, or the public will reject your product and eventually it will be taken off the market.

Assuming that the product's popularity increases, additional producers will begin to market the same item, creating competition for the primary producer. Profits at this point decrease and companies that can continue to produce a large amount of the product at an affordable price will thrive. Inevitably, the product will eventually lose popularity as new products are introduced (Mizrahi and Nerd).

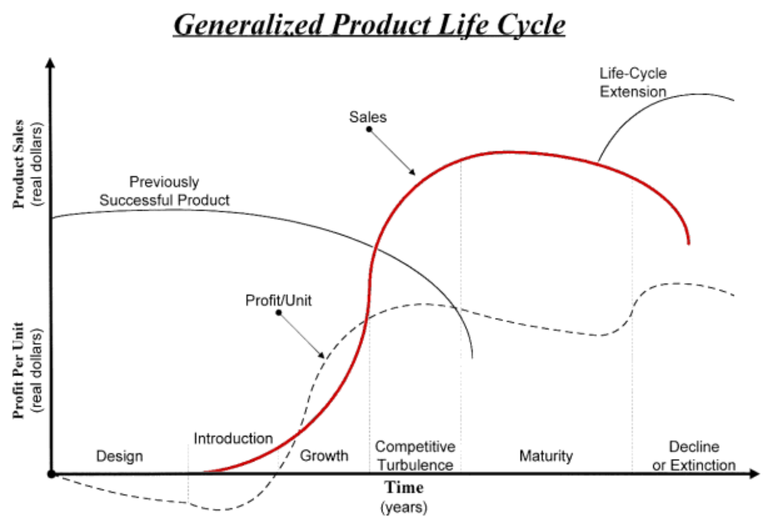

Figure 17: Product Life Cycle

When deciding whether to introduce new crops to a nation's market, it is important to consider the effects that the product profit cycle would have on the country's economy, especially when the new crop is intended to form the basis of that country's agricultural production; perhaps, these same principles could apply to a village. Considering Morocco's current economic state and the scarcity of water, it seems like the introduction of new crops would have enormous potential (Mizrahi and Nerd).

Israel-Morocco Germplasm Exchange- "Project M-20-018"

As in Morocco, the country of Israel has had problems attaining economically feasible amounts of water for irrigation. In an attempt to solve the country's floundering economic status, a group of scientists have collaborated to test 40 various species of trees known to flourish in arid conditions in the Negev and Judean deserts. The goal of the project is to identify those best suited to the desert climate, transplant them to Israel, and then market the most economically successful (Mizrahi and Nerd).

The project is comprised of two stages. Each species begins in the first stage during which certain characteristics such as the species' survival, growth, and yields are observed. Those that flourish in the desert conditions eventually move onto the second stage, in which the economic feasibility of mass-producing the crop is assessed. The researchers are hoping that farmers will consider the data they compile throughout their experiment and consider cultivating some of the species they have tested (Mizrahi and Nerd).

Currently, seven species have advanced to the second stage of the project. They are four species of climbing trellised cacti, the apple cactus, the white sapote, and the desert apple which is derived from India. Additionally, there are two other species that are about to be moved into the second stage.

As the climates of Israel and Morocco are very similar, it would not be unwise to consider transplanting the successful crops to the arid regions of Morocco. Another alternative is to run an experiment similar to that performed in Israel, by importing crops known to be drought-resistant, and then assessing those which are most viable (Mizrahi and Nerd).

In fact, researchers are already pursuing just that. In a project entitled, *Project M-20-018*, an exchange of germplasm between Israel and Morocco is proposed. If enacted, Israel will be able to transfer drought tolerant plants from Morocco, and Morocco will have at its fingertips the salt and drought resistant plants that Israel has already developed. The project also provides for the establishment of testing sites in both countries for which additional plants could be selected (USAID/MERC).

At the heart of the project are the hopes that Morocco will be able to produce enough crops to sustain itself while facing increasing levels of water scarcity and that the project and its after effects will provide a substantial amount of employment opportunities for the nation's citizens (USAID/MERC).

As we contemplate the introduction of new crops into the agriculture of Adghagh, we must consider the unique climatic conditions typical of the Moroccan Atlas region. Because winter temperatures often drop below freezing and the summer months are usually drought-ridden, it is important that the plant can survive both the extreme of frost and the extreme of water scarcity.

Prunus avium L. - Sweet Cherry

Growing wild in parts of western Eurasia and northern Africa (Martinez) at high elevations (Oukabli), the *Prunus avium* L., or the *Sweet Cherry*, has recently been cited as a potential alternative crop up for adoption by Moroccans. Biological classification of the sweet cherry is listed in Appendix I (United States Dept. of Agriculture).

Over the course of its 70-100 year life span, the cherry tree reaches, an average maximum height of 20-25 m and a trunk diameter of 50-70 cm. After initial implantation, the tree grows rapidly and experiences its first production of white blossoms and seeds in its fourth year. When the tree is 60-80 years old, it is considered to have fully matured (Russell).

Reproduction of the cherry tree begins with the production of seeds and usually occurs via insect pollination. An interesting aspect of the cherry tree is its ability to hybridize with other closely related species of cherries through cross-pollination. This attribute is of important note because it allows for the deliberate cross-pollination of trees with amiable genetic traits. In areas subject to environmental stresses, using hybridization to produce a variety of tree best suitable to the climatic conditions could encourage survival of the crop (Russell).

Figure 18: The Sweet Cherry

Keeping water conservation in mind, it is important to examine the hydrologic demands of the sweet cherry and its ability to survive in an environment nearly devoid of water. Though the cherry tree requires an ample amount of water to flourish, exposure to superfluous amounts of water can cause water logging, initiating destruction of the plant (Russell). Because the sweet cherry is harvested in late May of early June, it seems that the water shortage apparent in the summer will not pose difficulty to the crop's implementation in arid areas (Martinez).

In addition, the Prunus avium requires a great amount of sunlight to thrive and cannot withstand overly shady areas; certainly the long, dry summers and open flatlands of the

Adghagh village fulfill this requirement. The sweet cherry seems equally as tolerant of cold weather. Although late spring frosts can harm the organism, the tree can usually survive the majority of winter frosts. In fact cold weather can even be essential to the tree's survival; a certain frequency of cold temperature is necessary to trigger the release of seed from its 1-2 winter-long seed dormancy. The pH tolerance range is equally as versatile, spanning from a pH of 5.5-8.5 (Russell).

Each year, the beginning of the cherry tree's growth cycle is marked by a blossoming of white flowers. As the flowers continue to grow, leaves sprout around clusters of 2-6 flowers. The petals are then shed, and the red cherry fruit appears in its place, maturing until it is harvested in May or June, well before it would encounter the dry season of Morocco (Martinez).

Although the main and considerably most substantial effect of the adoption of the cherry tree crop would be the conservation of water and increase in income for the Adghagh villagers, it is also important to note the nutritional benefits that the crop could bring. The sweet cherry offers little in the ways of caloric content, but is rich in certain vitamins and minerals, especially potassium, which has shown to aid the heart, muscles, nervous system, and bones (Martinez).

According to statistics provided by the Food and Agriculture Organization (FAO), the profitability of the sweet cherry in Morocco has increased substantially over the past decade. In 1995, the producer price of the cherry in Morocco was around 10,000 *Local Currency Unit* (LCU) per ton, as compared the 2005 producer price of nearly 20,000 LCU per ton (FAO). A graph mapping out the changes in producer price over this time period is shown in Appendix J (FAO).

In addition, the opportunity available for Morocco to out produce its top three export countries to which it exports goods seems significant. As shown in Appendix K, Morocco's sweet cherry yield in hectogram/hectare surpasses both that of Spain and the United Kingdom as of 2007 (FAO).

Juglans regia L. - English Walnut

In its natural environment, the *Juglans regia*, or *English walnut*, is found at elevations as high as 3300 m in southeast Asia, southeast Europe, the Himalayas, and in China. However, through transplantation the species also grows in other parts of Europe and in the United States (Tropical Advisory Service). In Morocco, the English walnut is considered to be one of the most important cash crops by its people. Biological classification of the English walnut is listed in Appendix L (United States Dept. of Agriculture).

Over the course of the walnut tree's life span, it can reach heights of 27-30 m, and girths of 3.5-6.5 m (Tropical Advisory Service). The branches of the walnut tree stretch out vastly, ending in growths of white flowers that shed their petals to leave behind walnuts 2 inches in diameter. Upon harvest the walnuts are covered by an outer brown-shelled layer that protects the white and fleshier inside which is intended for human or animal consumption (Virginia Tech Dept. of Forestry).

Although the Juglans regia is capable of self-pollination, this method is rare and it is more likely that reproduction will occur via wind-pollination. Notoriously known for its gusty winds, it is likely that the Middle Atlas region would have no problem initiating natural reproduction of this organism.

Figure 19: The English Walnut

Again, because water is such a concern, it is most important to consider the amount of water necessary to irrigate any potential crop under consideration to be introduced into the Atlas Mountain region. Fortunately, as the English walnut is considered to have a moderate tolerance to drought, the availability of water is not a pressing concern (National Plant Data Center), requiring on average 600-800 mm of rainwater per year (Tropical Advisory Service).

Similarly to the sweet cherry, the English walnut cannot withstand subzero weather in the early spring, and even one late frost can destroy an entire season's crop. However, during the winter months when the organism is dormant, the tree can survive temperatures as cold as -35 degrees Fahrenheit. During the spring, summer and early fall when the organism is considered to be active, it can survive temperatures as low as -8 degrees Fahrenheit but will incur some damage, though not fatal. Because temperatures in Adghagh do not plunge below this temperature, the English walnut seems to be a viable option for the village (National Plant Data Center).

This crop requires a great deal of sunlight, so it must be planted in areas devoid of shade. Similar to the Prunus avium, excessive amounts of water can be damaging and the

English walnut will thrive in places where the soil is well drained. The optimum soil pH is one of 6-7.5 (National Plant Data Center).

The growth cycle of the English walnut begins with a sprouting of flowers in late spring, around the month of May. A growth of leaves occurs around the same time, and continues into June. Throughout the summer the trees continue to grow and will not lose their flowers and bear fruit until the late months of the summer and into early September, which will then ripen in October. The walnuts are ready for harvest in October, but can be harvested until the early weeks of November (British-Trees.com).

The English walnut also offers benefit in the way of nutrition for the people of Adghagh. They offer high caloric content, averaging about 647-657 calories per every 100 g and high levels of protein, averaging about 13.7-18.2 g of protein per every 100 g. In addition, the crop is also known for containing Omega-3 Fatty Acids, which are known to help with and prevent several diseases and health problems (United States Department of Agriculture).

Over the past ten years the producer price of the walnut has increased from around 1,000 USD per ton to just over 4,000 USD. According to these statistics, it seems that there may be great economic opportunity behind the English walnut, and likewise would be an excellent crop to introduce in Adghagh because of its high return (FAO).

Prunus dulcis L. - Almond

The popularity of, *Prunus dulcis*, or the almond, has skyrocketed over the last ten years with Morocco leading the way as the sixth highest producing country of the crop in the world (FAO). The biological classification of the almond is listed in Appendix O (United States Department of Agriculture).

Although the average life span of an almond tree is relatively short, around fifty years, the profitability of its lifetime yield is sufficient compensation for this shortfall. Four years after implantation the almond tree will begin to bear fruit, maximizing production after five (“Almond- Prunus dulcis”). When fully grown, the tree can reach heights of 3-7 m and bear fruit that is 1-2.4 inches wide. Its branches sprout ovular, narrow green leaves which surround light pink or whitish flowers when in bloom (United States Department of Agriculture).

Figure 20: The Almond

The species reproduces through cross-pollination identical to the reproduction methods of the almond and cherry tree. Consequently, this provides for greater genetic variety among trees (United States Department of Agriculture).

Highly compatible with the environment of Adghagh, the almond tree requires summers that are long, hot, and free of rain. Although it is generally tolerant of hot weather and drought, when water is scarce crop yield can be substantially lower. Akin to both the cherry and walnut, the almond can be destroyed by late spring frosts, but can survive small amounts of frost during winter. The ideal pH has been found to be 5.3-8.3 and the optimum temperature for growth is 10.5-19.5 degrees Celsius (Purdue University).

The growth cycle of the almond begins with the sprouting of light-pink or white flowers in the spring. The plant continues to grow throughout the summer until July-September when the crop is harvested. The need for harvesting is signaled when the shell of the nut breaks open, allowing you to see the nut inside (United States Department of Agriculture).

High in calories, the almond also offers a large amount of protein to consumers consisting of 19 g per every 100 g. In addition to this, the almond is rich in vitamins and minerals, especially riboflavin, phosphorus, and iron, which can all aid in preventing and treating diseases and other health conditions (“Almond- Prunus dulcis”).

Unfortunately, the producer price for almonds has steadily declined over the past ten years and is currently only around 300 USD per ton. According to this data, it is likely that the production of almonds will not bring in as high an income as walnuts and cherries, but is certainly still an option deserving further investigation (FAO).

In comparison to both Spain and France, two of Morocco’s primary export destination countries, Morocco has a greater yield in per hectare than Spain, but a lower yield in hectare than France. Thus, it is possible that Morocco may find opportunity in the international market to harvest and export almonds (FAO).

Before recommending solutions to solve the water crisis within Adghagh, it was necessary to investigate each aspect of the situation entirely. By examining periodicals, surveying relevant material at Al-Akhawayn University, and interviewing personal contacts we compiled the preceding background section of our paper. After accomplishing this task it was possible to begin formulating solutions that we would expect to be most compatible with the Adghagh villagers and their needs.

Chapter 3: Results and Findings

This chapter elucidates the results and findings from our examination of possible sustainable water management strategies in Adghagh. An analysis of current practices involving the use of both drinking and irrigation water showed that the village can potentially increase water availability by utilizing several techniques to improve water efficiency such as the use of alternative crops, improved irrigation methods, and water harvesting. Additionally, these long-term solutions may be complimented by short-term solutions such as deeper wells and the use of renewable energy to power these pumps, which would decrease the current economic strain on the village by reducing operating costs.

3.1: Meeting the Village's User Interface

One of the main responsibilities of the Interactive Qualifying Project is to address the needs and concerns of the people impacted by the project. All too often engineers and scientists develop beneficial and productive solutions to problems without properly assessing the needs of the individuals experiencing the problem. A specific goal of the Interactive Qualifying Project is "to create an awareness of socially related technological interactions," therefore while finding possible solutions to the problem of drought in

Adghagh we also took the desires and needs of the community into consideration in two main ways.

Village Meetings

Our first visit to Adghagh was originally going to consist of a quick tour of the village but we were very quickly invited into one of the households for mint tea and Moroccan pancakes. Josh Cabell, the Peace Corps Volunteer we worked with, explained the nature of our project to our host and based on their expressions and excitement we believed our project would be well received in the village.

The next visit we made to Adghagh was for a meeting with the village elders and the Community Association members. Also in attendance for this trip were Josh Cabell, Aicha Brahimi (the regional Peace Corps Director), Houssam Jedda, Professor Bland Addison, and the Adghagh IQP Team. The primary purpose of this meeting was to listen directly to the villagers. We discussed both the problem of drought and several options we thought of to remedy this problem. The villagers explained to us that the drought began in 1981, which is when they switched crops over to things like grains and apples. They also expressed their concern that the larger apple orchards uphill from the village have been draining the area's water table and therefore decreasing crop yields. The village elders were also enthusiastic about our project.

While meeting with the elders we discussed the current crops being used by the villagers. The main cash crop is the apple but potatoes, beans, peas, and plums are also grown, mainly for household consumption. While their main crop, apples is the most productive economically, it is not water efficient. There are many other cash crops that potentially could be grown in the village. In the meeting, crops such as cherries, walnuts, and almonds were discussed because they are able to grow in regions similar to Adghagh. Some of the villagers were hesitant about switching to crops other than apple trees, saying that “It is too cold in the winter” or that they “Wouldn’t survive the frost.” This is one of the problems engineers face on a daily basis, meeting the cultural and social needs of the client. While research has proven that cherries, almonds, and walnuts can be grown in Adghagh, the village is hesitant to look into alternative crops. To prove the effectiveness of this proposed solution, Josh has mentioned that there are actually already walnut trees in the village with plentiful yields.

In order to make the village more comfortable with the growth of alternative crops, a trial crop cycle could be implemented. This would involve some families to grow these crops in order to prove that they can be successful in the area. Based on the physical proof of a successful harvest, we would hope that other families would be willing to switch to the more water efficient cash crops in the future.

As we were leaving this meeting the village elders expressed their concern for the future of the village’s drinking water. Prior to this meeting the community association President had said that the main concern of the village was water for irrigation. This brought a new aspect to the Adghagh Project, finding plausible solutions for both concerns: drinking water and irrigation.

Adghagh Survey

Another method of exploring the needs and wants of the village was through a survey. To ensure that our project recommendations would serve the community’s needs, Joshua Cabell surveyed the village on their individual needs for and difficulties with water. The questionnaire consisted of seven questions regarding family size, distance to their source of drinking water, and crop irrigation methods. The final question of the survey was open-ended and allowed the families to provide any input they would like to give. The survey was written in English and translated to Arabic by Houssam Jedda.

To conduct the survey, Josh called a village meeting in order to address all the heads of the households at the same time. This meeting was the perfect opportunity to gather information because all of the 71 households were represented. The households are grouped into three main family groups and the head of each of these groups was asked to compile the survey information for his extended family.

Many of the households are between two and five kilometers from the drinking water well and less than five families are able to irrigate their crops using the water efficient method of drip irrigation. Through the survey, valuable information was gathered, allowing the village residents to empower themselves through the project.

3.2: Proposal of Water Efficiency Techniques

The current irrigation methods of Adghagh are severely limited by available water. For those who can afford it, water for irrigating crops is withdrawn from either a personally owned well, or from a neighbors. A majority of the over one hundred households however, cannot afford to drill their own well, or pay to withdraw water from their neighbor’s well.

In this case, rainwater is the sole source of irrigation. Several years ago, when the village's reservoir still supplied water, many of these households utilized irrigation ditches in the area, however they are now unable to do so.

Alternative Irrigation

Smaller households with less sizable farm plots do not have the monies to drill wells, or are simply too far away from other wells to utilize them. Therefore, these farmers must cope with what is immediately available to them, which is rainwater. Using rainwater at optimum efficiency is crucial in order to obtain the highest yields of crops possible. This can be done by expanding upon existing methods of ditch irrigation and row spacing. Ditch irrigation is an easy and cost free method of catching rainwater for the use in irrigation and is currently used by approximately ten households. Spreading the use of this irrigation method throughout the village would certainly improve water availability and should be considered by non-participating villagers.

The households in Adghagh that have wells and are able to utilize artificial irrigation methods also have potential for improving water availability. Less than five households of the community currently utilize drip irrigation and the rest use alternative, less efficient methods. One example of an alternative method being used in the village is well-fed modular piping. Utilized in orchards to water trees, this irrigation technique uses piping to supply water from the well to the trees and uses modular pipes without secure fittings. The pipes are simply placed into each other and a significant amount of water is lost in leakage between pipes. Since it is orchards like this that use the majority of the already diminishing groundwater, replacing these wasteful irrigation methods with more efficient forms means more will water reaches plants, which would increases crop yields. Complete system overhauls, while certainly favored for efficiency, are not necessary in each situation; small adjustments to existing methods can make a significant difference. In the case of the example mentioned above, adaption of inexpensive, non-leaking fittings would reduce water loss exponentially.

While the produce of some households supply them with only enough money to sustain themselves, larger households who own wells are more likely to have capacity for improving their existing systems. Because of their larger farming area and wealth, they would benefit further from a more automatic, highly water efficient, and low evaporation irrigation method such as drip irrigation. As mentioned before, less than five households in the village currently utilize drip irrigation; all of whom own the most successful land in Adghagh (Cabell). As shown in the survey conducted by Josh Cabell, families have shown interest in implementing drip irrigation but often lack the resources to purchase the system. Further interest by the community is testament to its success in both the area and elsewhere. Not only does drip irrigation use significantly less water, but also its source to root design can increase crop yields by 200% (Stanhill). The recent decrease in water availability has crippled crop yields, so a promise for improvement in produce is the driving factor in the community’s desire for the system.

Water Harvesting

The use of water harvesting, also known as water catchment, has great potential in serving the community’s needs. While many households rely solely on rainwater to irrigate their crops, none exploit this promising drinking water retrieval method. While

Morocco as a whole and Adghagh especially are suffering from a decrease in precipitation, Morocco is still only classified as a Group II country (IWMI). Annual rainfall has averaged 346mm per year between 1998 and 2002, which is significantly high compared to other arid countries in the Middle East and North Africa (Making the Most of Scarcity). Even more hopeful, is that between August and October of 2008, while the project work was being conducted, the Adghagh area experienced a great deal more precipitation than usual. Because of the moderate levels of precipitation and near complete absence of surface water in the area, Adghagh is an excellent candidate for this means of water procurement.

Water harvesting is a popular technique to supplement other water sources, mainly because of its low installation cost, low maintenance, and ease of use. In its simplest form, water catchment devices can be placed atop of homes and storage tanks are kept at ground level for easy access. Water would be used primarily as a source of household water and due to its high quality, can be used for human consumption as drinking water without treatment (Ross).

Improving water availability for drinking and household use would be a very important enhancement to the quality of life in Adghagh. Again, most households in Adghagh do not have access to a well, so household water is not readily available. As a result, children are enlisted to retrieve water daily from a public well on the main highway. The distance needed to transport water varies between two and five kilometers each way depending on the location of the household. This presents an important social issue, because while children are occupied completing these laborious chores, they can miss schooling. If water catchment is utilized, more water will be readily available at each household and parents will have less need to remove their children from school. This of course would allow the pursuit of the much more important issue of education.

Well Management

Wells in Adghagh are crucial to supplying water for both drinking and irrigating crops. Currently, the village has several wells, one of them being public and seven others which are privately owned (Cabell). While the public well may be used by any of the villagers, it requires the use of a diesel pump, and fuel must be provided by the user in order to run it. The other wells of the village are privately owned by single households and are often shared to distribute water to neighbors. Because of the dependence on wells for irrigation, especially for larger fields, it is vital that their health be maintained.

The area of Adghagh and the Sebou basin as a whole are both facing the grave issue of water scarcity. Ground water withdrawal is exceeding replenishment, causing the water table to lower. As water tables approach critically low levels, now more than ever it is important to responsibly monitor well extraction rates to prevent premature terminal consumption of the well. Lowering water tables are threatening the health of these wells, so to prevent unnecessary redrilling, withdrawal rates should be kept to reasonable rates. If faced with a further decline in precipitation in the future, increasing extraction rates would only compound the troubled water table and likely result in expended wells. Increasing the withdrawal rate of a well not only strains the water table, but it also amplifies the well’s cone of depression, causing a decrease in water recharge to the well.

3.3: Decreasing Available Water: Causes and Effects

Water availability in Morocco has been rapidly decreasing over the past thirty years. Particularly in the Sebou Basin and even more so in the area surrounding Adghagh, water tables are lowering and surface water is disappearing. The ongoing drought can be attributed to a consistently low level of precipitation and a complex of other issues that is leaving Morocco with low levels of water input. Conditions are not predicted to improve, and estimated precipitation is predicted to decline by approximately 4 percent over the next twenty years.

The current decrease in precipitation, which is the overriding instigator of drought, causes a positive feedback loop for agriculture in Morocco. Decreasing levels of available water drive farmers to find other sources of water to make up for irrigation lost from ordinary rainfall. Farmers in Adghagh had been utilizing the village’s reservoir and since it has been exhausted, those who are able have turned to withdrawing well water. In the last decade especially, villagers have been withdrawing water at much higher rates to the extent that rates of withdrawal have greatly exceeded rates of replenishment.

With respect to the capacity of the Sebou Basin, the magnitude of water withdrawal by the Adghagh community is exceptionally small. In contrast, newly implemented large-scale commercial orchards in the Basin have been using incredible volumes of water resources. The orchards, which have been planted within the last ten years, are exponentially larger than any farming areas seen in this area before. They encompass vastly large yields that are increasingly important to the development of Morocco, but its deep wells are draining the area’s aquifers and *embezzling* water resources from smaller farming areas like Adghagh (Kalpakian).

Since groundwater abstraction is exceeded by replenishment, the water table is continuing to lower. This reduction in water table depth is also causing the natural springs to turn inactive. The rate of excessive withdrawal is now so great that artesian pressure from the confined aquifer under the village is no longer able to supply underground water to the reservoir. As this continues, the shallow wells of the village, both public and private, will run dry. The villagers may be able to redrill a number of times, but unless usage or replenishment rates improve, redrilling will become routinely necessary and financially impossible. Furthermore, according to an unreleased report produced from within Al-Akhawayn University, aquifers may drop below accessible levels within twenty-five years and water will no longer be available altogether (Kalpakian).

3.4: Recommendations to the Adghagh Community

Overall the results of the project have been divided into short and long-term solutions. The issues of both irrigation and drinking water were addressed in order to meet the interests of the people of Adghagh.

Short Term Solutions

In order to provide drinking water to Adghagh, a well with a solar-powered, submersible displacement pump is the most feasible solution. Solar energy has been used to power pumps in similar situations and would likely be a wise choice for use in the village. The displacement pump, unlike the centrifugal pump, is ideal for this situation due to the proposed depth of the well, a minimum of 160 meters. Also, due to the extreme winter weather conditions in Adghagh, a submersible pump would work well. Submersible pumps can withstand extreme cold and frost because they are located deep within the well itself.

Funding for the implementation of this well could possibly be provided by a grant from a non-governmental organization. In the past NGOs have funded similar projects and with the implementation of a pump powered by renewable energy there is an even greater likelihood that the well in Adghagh could be funded by an outside organization.

Long Term Solutions

Long-term solutions include potential resolutions for both the drinking water and irrigation problems. Probably the best option to resolve the drinking water problem would be to implement a rainwater-harvesting program. While the region received little rainwater as a whole, catchment would serve as a supplemental resource for drinking water in the village. Additionally, snowfall received during the winter could also be used with the catchment system; however water would only be caught as the snow melted. This system would be relatively low cost to implement and would provide the villagers with water that is currently going to the ground.

In order to address the problem with irrigation water we have devised two possible solutions. The current irrigation methods within Adghagh waste a great deal of water on a daily basis. Therefore, by updating and improving these methods, irrigation could become much more efficient. In order to do this, the farmers of Adghagh should consider implementing drip irrigation systems. While several households currently use this system, there are many more that could benefit from its use. This practice is the most efficient irrigation method available and also has a low implementation cost.

Another long-term option for improving water use with irrigation in Adghagh is to experiment with more water efficient crops. After a great deal of research, the crops which we recommend for the village are cherries, walnuts, and almonds. In order to begin this process a trial crop cycle where one or two households attempted to grow these crops would be valuable. This would increase community confidence in the crops and hopefully convince other families to begin growing these crops. Through these methods Adghagh should be able to remain growing crops in their village for years to come and become more successful farmers.

Chapter 4: Conclusion and Recommendations

Based on the research and data collected throughout the Adghagh project we have concluded that there is great potential for the improvement of water efficiency within the village. The villagers currently rely on an inefficient system of wells, faucets, and canals to provide both drinking water and irrigation water for their households. With some improvements in both areas, Adghagh could be much more successful in meeting their needs and also economically based on the cash crops grown in the area. The information gathered about water use in Adghagh has allowed us to make both short and long-term recommendations regarding drinking water and irrigation water.

Improving Accessibility to Drinking Water

In order to improve on the accessibility of drinking water within Adghagh, villagers should take advantage of water harvesting techniques and should look into drilling a deep, public well. Currently, water harvesting is not used at all within the village; there is a public well within the village and a public faucet approximately 3 km away from most households.

Water harvesting is a simple technique that can be easily implemented into most living situations. While drought continues in Adghagh, there are still adequate rains during the spring and occasional rains in the summer and fall. While this precipitation supplies much need water to the villages crops, it could also be caught and used as a supplement for drinking water within the village. Water catchment systems simply consist of a catchment device, a reservoir, and a tap. The catchment device is easily added to the roof of a building, the reservoir can be made of an ordinary oil drum, and the tap attaches to the reservoir. This is a lower cost system that would be easily implemented in the financially stressed village of Adghagh.

Currently many of the villagers use public wells and faucets to obtain drinking water but these wells are drying up fairly quickly. In order to meet the needs of drinking water within the village we have found that a deeper well powered by renewable energy would be a valuable resource for the community. Based on information gathered in a village meeting, the well would need to be a minimum of 160 m deep. Due to the ground type in the area, simple hammer drilling could be used for this well, which costs approximately 500 Moroccan Dirhams per meter. The total cost of drilling this well would be 80,000 Moroccan Dirhams or 9673.52 USD (based on the exchange rate of 8.27 MAD per one USD on 10/16/2008). In order to pump water from a well of this depth, we found that a submersible displacement pump would be most effective. Not only can this pump configuration raise water from great depths, but it can also withstand extreme weather conditions faced in the harsh winters of the Middle Atlas Mountains. Due to the high costs of fuel in today's world, we recommend powering this well by renewable energy resources. Solar energy appears to be the most practical resource in this case due to the well depth along with the fact that solar energy has been used prior to the Adghagh project to power wells in similar situations. The cost of this project is out of reach for the village of Adghagh on its own so we recommend attempting to gain funding through non-governmental organizations. NGOs have provided funding in similar projects in the past and with the implementation of the environmentally friendly solar panels, they are even more likely to financially support this endeavor. Though the implementation cost of this system would be somewhat high, the overall running costs would be very low and would create an easily accessible resource for drinking water in the village.

Water Efficiency and Irrigation

In order to ultimately succeed as farmers through the increasing drought in the Middle Atlas, the people of Adghagh will need to improve upon current irrigation methods and adjust their crops and lifestyles to more water efficient methods. Techniques such as drip irrigation and alternative crops should be used in order to preserve the little water Adghagh has available.

Currently less than five families take advantage of the most effective irrigation method, drip irrigation. Though it would be slightly costly for the families to implement this system into their fields, it would drastically increase their water efficiency. Most families use modular pipes that fit together loosely and leak excessive amounts of water, losing it to the ground. Through the use of drip irrigation more of this water could easily be used for its purpose: the watering of crops. This method has already been proven to work in the village through the few families already taking advantage of drip irrigation.

Another possibility to improve on water efficiency in Adghagh is to switch to crops that require less water. The apples currently grown require a lot of water, and since sufficient irrigation is unavailable, the orchards deliver minimal yields. Other possible crops are cherries, almonds, and walnuts; all of which have the potential to be successful in the Middle Atlas region. The difficulty this solution faces is resistance to change maintained by the villagers. In dialogue between team members and the village elders, they expressed concern about the growth of these crops in their village. From the information we gathered, Adghagh has had no prior experience with these crops besides walnuts, which currently grow in a few places around the village. Because the research done by our team has shown that these crops have potential in the area, we believe that a *trial cycle* of the crops would be valuable in order to prove their success for the villagers. This trial cycle would involve a few families growing the alternative crops for a few years, hopefully with great success and large yields. If this were accomplished, hopefully other families would consider switching their crops to the water efficient crops, which would ultimately conserve water within the community and increase water availability.

Through the implementation of these recommendations, the villagers of Adghagh would hopefully be able to obtain drinking water more easily, efficiently grow and irrigate crops, and increase the yield and financial stability of the village. The techniques we have recommended have been successfully used in other parts of the world and we believe would be valuable adaptations in the village of Adghagh.

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Appendices

Appendix A

Figure 21: Satellite Imagery of the Entrance and Reservoir of Adghagh

Figure 22: Satellite Imagery of Adghagh's Reservoir


Primary Spring
Spring 3
Spring 2
Spring 1
Middle of Reservoir
Base of Dam
Water Tower
Village Well
Google
Image © 2008 DigitalGlobe

Figure 23


Google
Public Well
Josh's House
Base of Dam
Village Well
Image © 2008 DigitalGlobe

Figure 24

GPS Survey of Adghagh, Morocco		
Location	**GPS coordinates**	**Altitude (m)**
Base of Dam	33° 36.720 05° 05.765	1481
Middle of Reservoir	33° 36.701 05° 05.726	1483
Bottom of River		1481
Spring 1	33° 36.638 05° 05.600	1484
Spring 2	33° 36.649 05° 05.589	1485
Spring 3	33° 36.641 05° 05.580	1486
Primary Spring	33° 36.637 05° 05.554	1488
Water Tower	33° 36 707 05° 05.815	1485
Public Well	33° 36.694 05° 05.856	1481
Faucet 1	33° 36.711 05° 06.210	1467
Faucet 2	33° 36.998 05° 05.938	1475
Faucet 3 (Josh's)	33° 36.782 05° 05.864	1483

Appendix B

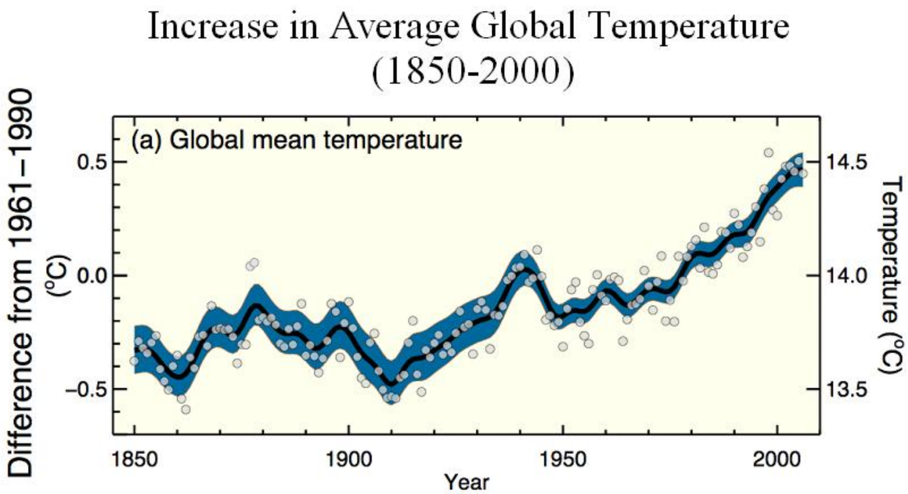

Figure 25: A Graph Representing Global Temperature Change

Appendix C

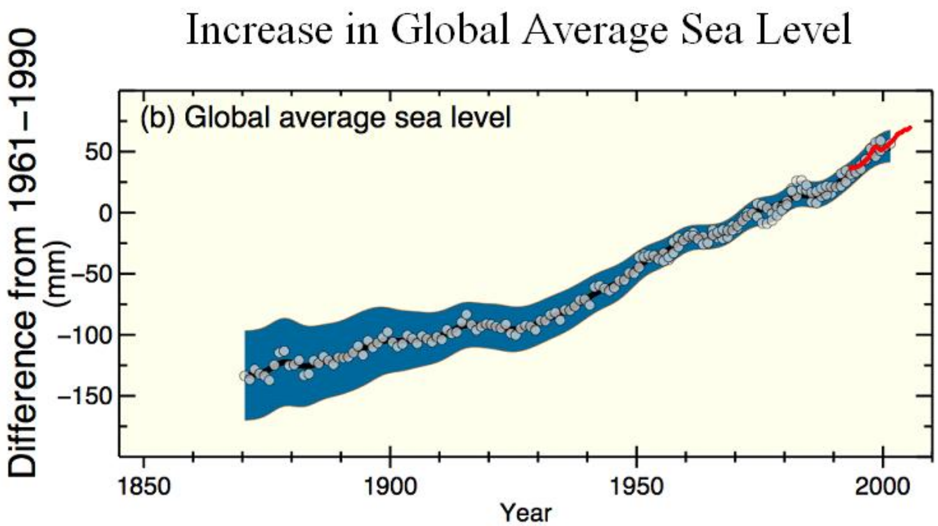

Figure 26: A Graph Representing Global Changes in Sea Level

Appendix D

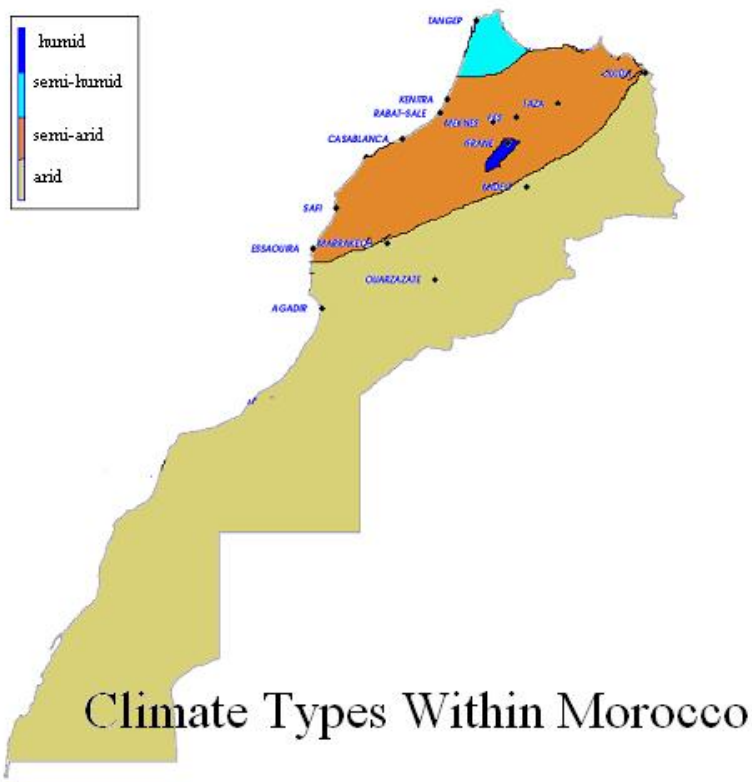

Figure 27: A Map of Morocco Showing Various Climate Regions

Appendix E

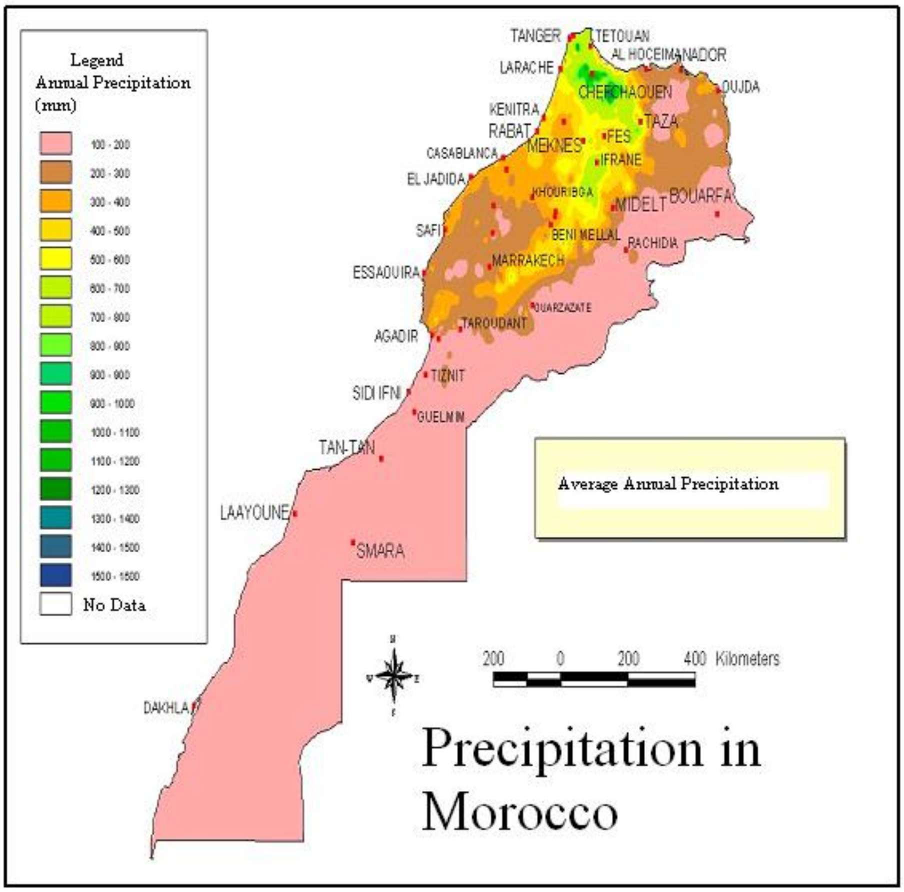

Figure 28: A Map of Morocco Showing Precipitation Levels

Appendix F

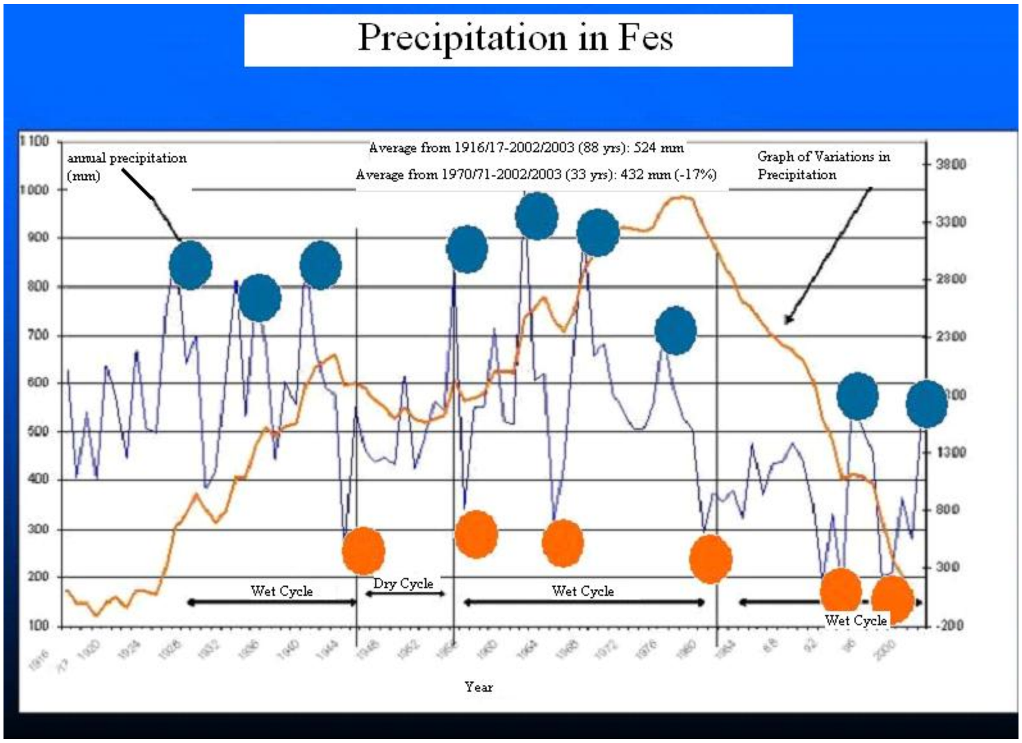

Figure 29: A Graph Representing Precipitation in Fes, Morocco

Appendix G

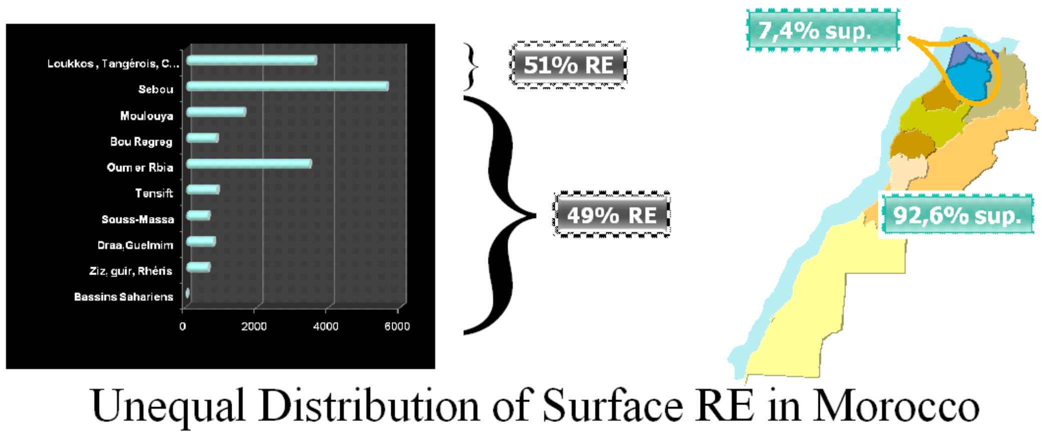

Figure 30: A Table and Map Representing Surface Resources in Morocco

Appendix H

Historical Evaluation of Water Resources in Morocco

First Evaluation (1984): 30 billion m^3

Second Evaluation (1995): 29 billion m^3

Third Evaluation (2006): 22 billion m^3

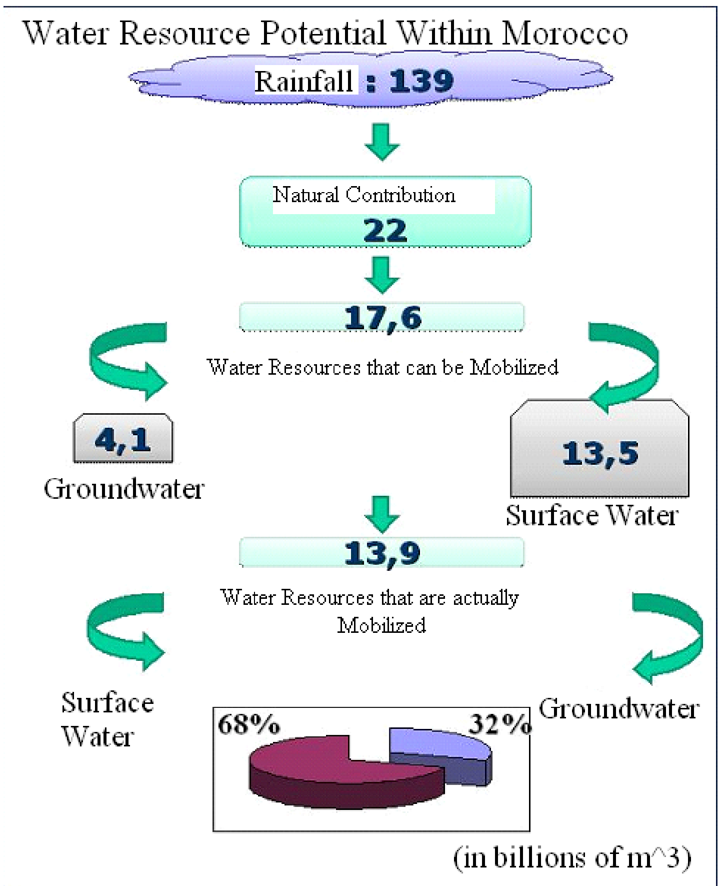

Figure 31: A Diagram Representing Water Resource Potential in Morocco

Appendix I

Classification:
Prunus avium (L.) L.

Kingdom	*Plantae* – Plants
Subkingdom	*Tracheobionta* – Vascular plants
Superdivision	*Spermatophyta* – Seed plants
Division	*Magnoliophyta* – Flowering plants
Class	*Magnoliopsida* – Dicotyledons
Subclass	*Rosidae*
Order	*Rosales*
Family	*Rosaceae* – Rose family
Genus	*Prunus* L. – plum
Species	*Prunus avium* (L.) L. – sweet cherry

Figure 32: A Table Describing the Classification of the Sweet Cherry

Appendix J

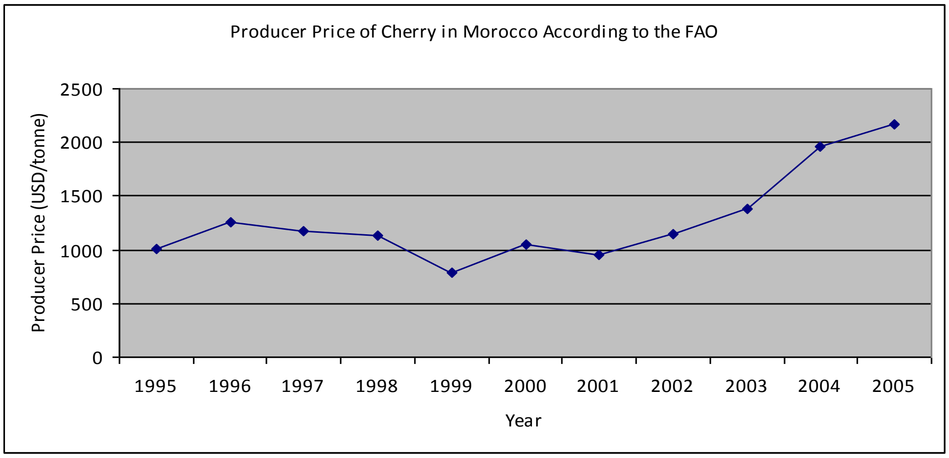

Figure 33: A Graph Representing Producer Price for Sweet Cherries in Morocco

Appendix K

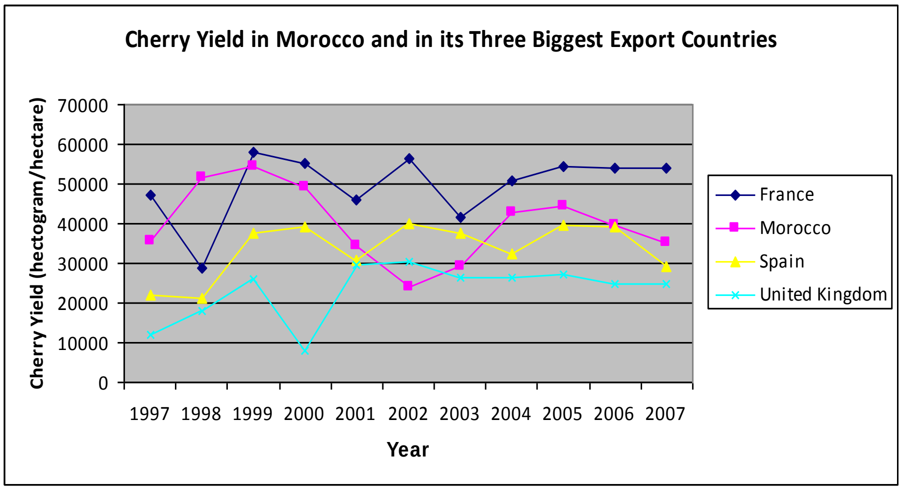

Figure 34: A Comparative Graph Representing Sweet Cherry Yield in Morocco

Appendix L

Classification:
Juglans regia (L.) L.

Kingdom	*Plantae* – Plants
Subkingdom	*Tracheobionta* – Vascular plants
Superdivision	*Spermatophyta* – Seed plants
Division	*Magnoliophyta* – Flowering plants
Class	*Magnoliopsida* – Dicotyledons
Subclass	*Hamamelididae*
Order	*Juglandales*
Family	*Juglandaceae* – Walnut family
Genus	*Juglans* L. – walnut
Species	*Juglans regia* L. – English walnut

Figure 35: A Table Describing the Classification of the English Walnut

Appendix M

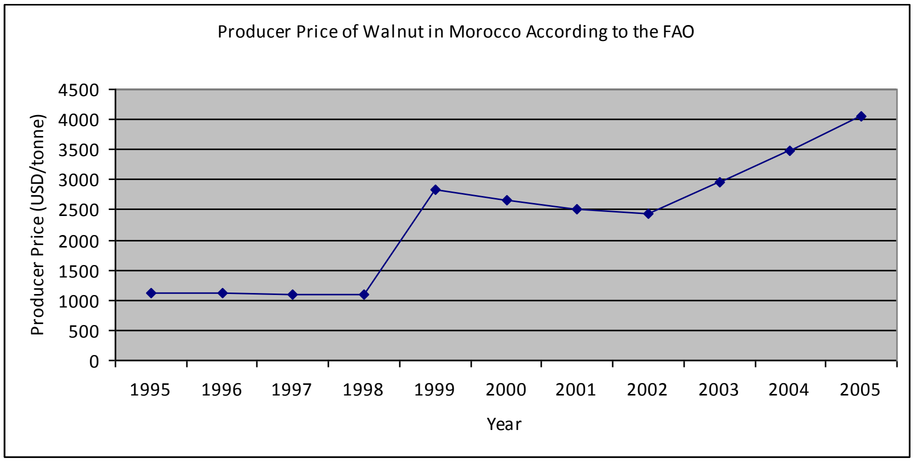

Figure 36: A Graph Representing Producer Price for the English Walnut in Morocco

Appendix N

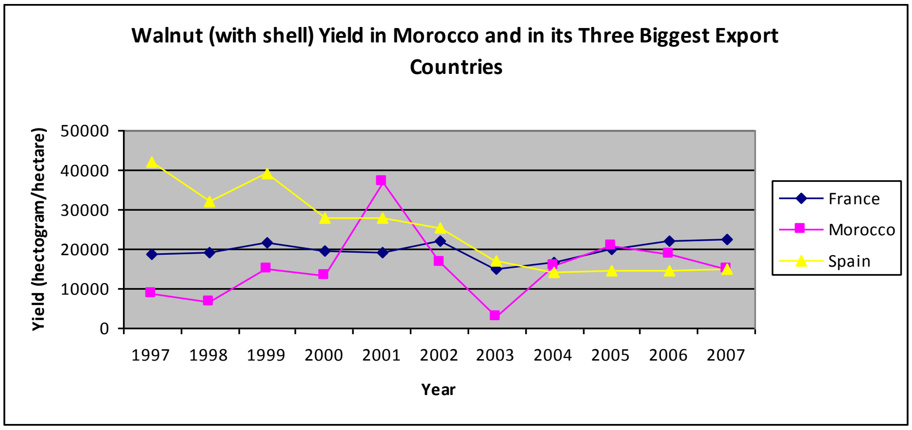

Figure 37: A Comparative Graph Representing English Walnut Yield in Morocco

Appendix O

Classification:
Prunus dulcis (L.) L.

Kingdom	*Plantae* – Plants
Subkingdom	*Tracheobionta* – Vascular plants
Superdivision	*Spermatophyta* – Seed plants
Division	*Magnoliophyta* – Flowering plants
Class	*Magnoliopsida* – Dicotyledons
Subclass	*Rosidae*
Order	*Rosales*
Family	*Rosaceae* – Rose family
Genus	*Prunus* L. – plum
Species	*Prunus dulcis* (Mill.) D.A. Webb – sweet almond

Figure 38: A Table Describing the Classification of the Almond

Appendix P

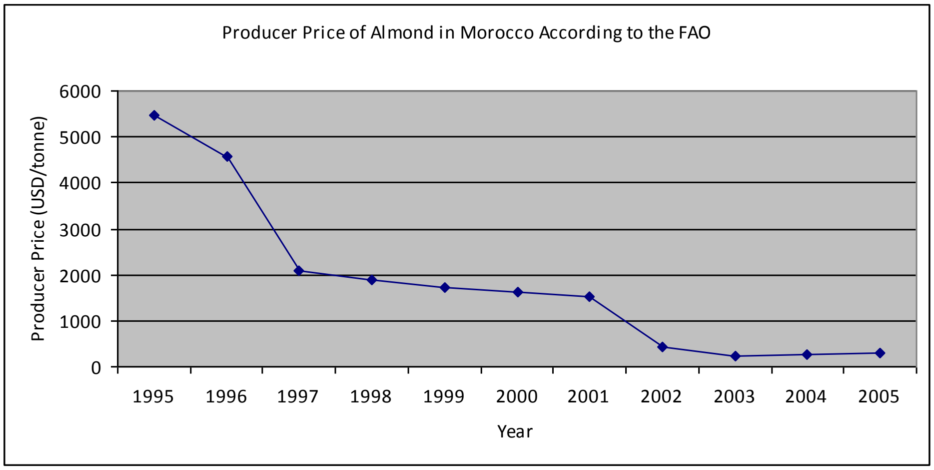

Figure 39: A Graph Representing Producer Price for the Almond in Morocco

Appendix Q

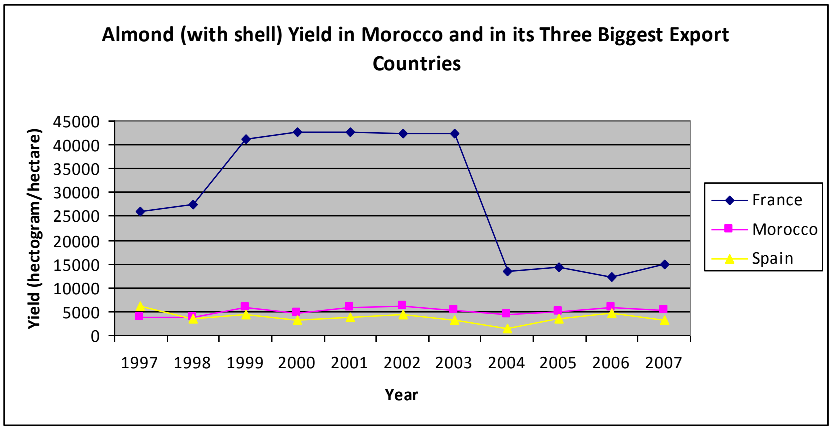

Figure 40: A Comparative Graph Representing Among Yield in Morocco

Appendix R

Transcript from Meeting with Adghagh Elders, Sept 3, 2008

-The village needs ways of getting more water and using it more efficiently

-Local apple orchards are lowering the water table

  -More water is probably not enough to solve the problem; they still need more efficient crops

-Wells must be 160-meter deep wells to reach water

  -Drilling cost is1000dh per meter

  -Hammer-Drill cost is approx 500dh per meter

    -The bedrock is mostly limestone, so drilling is much cheaper than it would be if the rock were granite

  -They are more likely to get money from NGOs if they utilize more efficient systems for irrigation and pumping (drip irrigation, solar power, and wind power)

    -They would require a complete proposal with mapped canal system, plan for efficient use, funds needed, and amount of water required

-They would like to implement trees, possibly 'nutsor' cherry trees

  -These trees need less water and yield comparable profits

  -Additionally, they can plant crops under the trees to protect against sun and erosion

  -Potatoes, beans, peas, plums, apples are their current crops but the village currently consumes more then they produce

  -Primary cash crop is the apple, but it needs the most water

-Few areas currently have drip irrigation. Expansion of this system to other households is desired

-Village elders claim the weather can at times be too cold for walnuts and almonds (*Josh claims this is incorrect*)

-Village currently only uses solar power for lighting but with enough panels, they could operate a low voltage pump

-Water collection

  -Not used, but the village receives enough rain snow to make it feasible

-NGO = non government organization

-If utilizing solar power, it may be easier to get funding from the NGOs

-They don't have enough food for animals because of lack of water (barley)

-They want to improve the spring that feeds the lake and claim that the dam caused the problem (*Doesn't seem reasonable*)

-Where is the water underground? Can villagers redrill? Is surveying possible? How much would it cost?

-Need to look into groundwater and accessibility

-Apple orchards uphill are draining water tables near Adghagh

    -They have very large fields which use a lot of water and are likely drying up other springs

-The drought started around 1981, so they began harvesting apple trees (*not a good decision since apple trees require a lot of water*)

-Often wholesale companies come to Adghagh directly to collect harvests. They don't receive as high of prices for produce as the larger orchards

    -Harvest this year may not even be marketable

Appendix S

Transcript from Meeting with Josh Cabell, Sept 4, 2008

-The Basin was fed by the natural spring near the gravely area at the top of the reservoir. There were many small springs, and one larger one which originated higher up the hill

-People have been working less because of the lack of water and prefer to be working more. Kids retrieve drinking water, so water retrieval is not affecting the working men

-Some family wells are deep enough now for normal use and are okay for watering the orchards

-Unless the spring is planning on being redrilled, there is no need for a GPS survey (It would be part of a proposal to receive money for the drilling

-The pipes for the water pump and tower are definitely too small at the main well
  - -They claim that the small pipes are causing the pump to work too hard.

-Priority of the community is to fix drinking water problem

-Priority of the association is to fix the irrigation water problem
  - -Community may want to first start with a simpler project like drinking water
  - -However, self-sufficiency may be more important than the inconvenience of retrieving drinking water
  - -The village's sources of irrigation water: wells and the public well on the highway are also suitable for drinking water

-Along with finding more water to use, water efficiency education is definitely needed

-More efficient methods of orchid irrigation are necessary (currently use modular pipes without fittings)

-Elders are expressing high interest for a solar/wind system for the school well
  - -Will make it easier to get funding from NGOs
  - -Need to look into a maintenance program
  - -Electric company that offers solar program is 'O.N.E.'
  - -Wind power option – a mechanical design would be preferable

-Village may give alternative crops a chance
  - -We may be able to convince several households to begin a test plot

-Walnuts can be harvested in Morocco (they are often grown in this area contrary to what was said at yesterday's meeting)

  - -Cherries, walnuts, almonds

-Cherries ripen earlier (June) opposed to apples (Oct)

-Village wants to redrill the spring but has no funding to do so (*this is not a logical well location regardless*)

-There has been a yearly decline in wheat and barley

-Currently, the village's primary income is in sheep and apples

-Some men work as laborers in town

-They are also selling land, which is not a solution (only a temporary solution)

-Only a couple of families with drip irrigation

-Cost to implement is around 1000-2000dh per acre (non-taxed)

Appendix T

Questionnaire

Family Name?

Size of family?

Water source for drinking water, distance? Children retrieving water?

Size of Farm?

What are your crops?

Water source for irrigation, distance? Type of irrigation? Drip?

What do you need to improve conditions of water availability?

Appendix U

Moroccan Arabic Questionnaire

شنو سميتك او كنيتك

شحال بيكوم في العائلة

منين كاتجيبو لما اوشكون كايجيبو واش الدراري الصغار

شحال المساحة ديال أرضك

شنو كاتزرع فلأرض ديالك

منين كاتجيب الما باش تسقي أرضك أو شحال ديال المسافة بعيد هاد الما

كيفاش كاتسقيو واش كاتدير غوت أ غوت

شنو فنظرك خاص يدار باش نزيدو لما او لا نلقاوه

Appendix V

Survey Results

Irrigation Source	Size of Farm (hect)	Crops	Drinking Source (km)	Size of Household
Rain	2	Grain	3	5
Rain	2	Grain	3	7
Rain	1.5	Grain	2	7
Rain	1.5	Grain	3	6
Rain	1.5	Grain	3	5
Rain	5	Grain	3	7
Rain	2	Grain	2.5	8
Rain	7	Grain	3	5
-	-	-	1 well	10
Rain	7	Grain	well low	12
Drip	400	Grain, Veg, Fruit	well low	15
Rain	30	Grain, Fruit	3	28
Rain	7	Grain, Fruit	3	7
Drip	16	Grain, Veg, Fruit	well low	12
Drip	16	Grain, Veg, Fruit	well low	8
Rain	1.5	Grain	3	13
Rain	4	Grain	3	10
Rain	2	Grain	3	13
Rain	1	Grain	3	9
-	-	-	well p	2
-	-	-	well p	4
-	-	-	well p	7
Rain	1	Grain	well o	4
Rain	4	Grain	well o	6
Rain	5	Grain	well o	4
-	-	-	well o	4
-	-	-	well o	4
Rain	25	Grain, Apples	well o	14
Rain	25	Grain, Apples	well o	18
Ditch	21	Grain, Fruit	well t	15
Rain	9	Grain	well o	7
-			well o	4
Rain	1	Grain	well o	5
Rain	1.5	Grain	well o	5
Ditch	2	Fruit	well t	7

Rain	9	Grain	well o	8
Rain	7	Grain	well t	6
Rain	3	Grain	well o	5
Rain	1.5	Grain	well o	4
Rain	2	Grain	well o	10
Rain	3	Grain	well o	8
Rain	1.5	Grain	well o	5
Ditch	7	Grain, Potatoes	well t	6
Ditch	6	Barley, Wheat, Apples, Onions, Potatoes	well t	13
Rain	50	Barley, Wheat	4	9
Rain	50	Barley, Wheat	4	7
Rain	10	Barley, Wheat	4	10
Rain	9.5	Barley, Wheat	4	8
Rain	15	Barley, Wheat	4	4
Rain	13	Barley, Wheat	4	10
Ditch	45	Barley, Wheat, Fruit, Veg	well	15
Rain	40	Barley, Wheat	well o 1.5	10
Rain	25	Grain, Apples	well low	10
Rain	14	Grain	well o 1.5	6
Rain	14	Grain	well o 1.5	8
Rain	4	Grain	well o 3	8
Rain	6	Grain	well o 3	12
Ditch	25	Grain, Veg.	well t	12
Ditch	16	Grain, Veg.	well t low	14
Rain	20	Grain	well o	13
Rain	4	Grain	4	6
Ditch	16	Grain, Veg.	well t low	12
-	-	-	well o 2	3
Rain	1.5	Grain	well o	9
-	-	-	well o	3
Rain	2	Grain	well t	8
Rain	2	Grain	well o	5
Rain	3	Grain	well o	5
Rain	2	Grain	well o	5
-			well o	5
Rain	2	Grain	well o	5
Rain	16	Grain	well o	5
Rain	1.5	Grain	well o	4
-	-	-	well o	4
Rain	5	Grain	well o	9
Rain	5	Grain	well o	7

Rain	3	Grain	well o	7
Rain	9	Grain	well o	5
Rain	1.5	Grain	well t	5
Rain	4	Grain	well o	2
Rain	1.5	Grain	well t	3
Rain	1.5	Grain	well t	4
Rain	1.5	Grain	well t	2
Rain	2	Grain	well o	6
Rain	11	Grain	well o	14
Rain	3	Grain	well o 2	6
Rain	220	Grain	well o	5
Rain	150	Grain	3	7
Rain	30	Grain	3	4
Rain	5	Grain	5	7
Rain	80	Grain	3	14